NASA-CR-167726

Active Microwave Remote Sensing Research

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PROGRAM PLAN

JUNE 1980

NASA

Recommendations of the

Earth Resources Synthetic Aperture Radar

Task Force

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PREFACE

This Active Microwave Remote Sensing Research Program Plan is the culmination of an intensive nine-month effort involving over 100 scientists and engineers. The result is a carefully structured program of research and development designed to clearly establish the value of synthetic aperture radar image data in a number of specific application areas. The need for proceeding vigorously with this program is due in part to the challenge from foreign governments for scientific and technological leadership in this important field, and from the recognition that visible/infrared remote sensing, although enormously useful, is unable to fully address the data needs in several important applications areas. The indication that active microwave remote sensing techniques have the potential to satisfy specific earth observations data needs, particularly in cloudy environments, is thoroughly documented by a series of annual studies sponsored by the Johnson Space Center beginning with the Active Microwave Workshop in 1974.

This planning activity was conducted by the ERSAR (Earth Resources Synthetic Aperture Radar) Committee which was established by NASA in 1979 to define the role of active microwave sensors for future earth resources observations programs. The Committee is composed of a Steering Committee and various Working Groups. The ERSAR Applications Group Workshop, held November 7-9, 1979 in Houston, Texas, and the ERSAR Program Definition Group Workshop, held January 23-25, 1980 in Pasadena, California, were two major elements in a series of working sessions to develop this program plan. The two workshops involved over 80 recognized experts in the topic areas of concern.

This document is strongly dependent on the Program Definition Workshop Report (Appendix B). The tasks identified in this plan are those specified in the earlier report. Consequently, this plan omits the detailed description of each task and the background material which provides the justification and/or role of each task in the overall effort. The objective of this report is to provide a structure for a coordinated effort that will optimize the overall approach to conducting the research program recommended by the Program Definition Working Group. The Applications Workshop Report is also included (Appendix A).

The dominating influence shaping this program plan is the present lack of adequate measurement systems needed to conduct the required experiments. This serious deficiency inhibits an aggressive attack on the several problem areas where fundamental information is needed to support evaluation and validation of the sensing technique. Consequently, the plan specifies empirical studies in those cases where measurements are possible; stresses theoretical modeling studies preparatory to empirical verification in those cases where measurements are not possible at this time; and places high priority on acquiring the data acquisition systems needed to support a viable basic research program.

This program plan was structured during the Plan Development Workshop held February 18-20, 1980 in Greenbelt, Maryland. This third workshop in the present series was attended by the ERSAR Steering Committee members. The Program Plan provides the basis for an Active Microwave Research Program Implementation Plan.

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SUMMARY

It is well recognized that microwave remote sensing techniques have unique characteristics which appear to possess significant potential fo: earth observations of renewable and non-renewable resources. Several foreign countries, notably Canada, Japan, and West Germany, have initiated vigorous programs to exploit the potential of microwave sensors. Industry-operated airborne imaging radar sensors have been employed to collect data on millions of square kilometers in the U.S., South America, and Africa for use in geologic mapping and general resource inventories. A major airborne radar image survey program is presently underway in Alaska. The Seasat microwave sensor data clearly illustrated the enormous potential of these techniques, particularly for observation of the oceans.

Despite these activities, and the fact that the potential of microwave remote sensing has been documented in several extensive studies conducted over the last decade, the existing research results are inadequate to satisfactorily demonstrate the measurement capabilities of active microwave sensors, particularly imaging radar sensors, for applications of primary interest. This situation exists because very little research in this topic area has been sponsored in recent years due to the concentration of available funds on Landsat and other visible/infrared remote sensing programs.

This research program plan was developed by the Office of Space and Terrestrial Applications to provide guidelines for a concentrated effort to improve the understanding of the measurement capabilities of active microwave imaging sensors, and to define the role of such sensors in future earth observations programs. The focus of the planned activities is on renewable and non-renewable resources. Five general application areas are addressed: 1) vegetation canopies, 2) surface water, 3) surface morphology, 4) rocks and soils, and 5) man-made structures. Research tasks are described which, when accomplished, will clearly establish the measurement capabilities in each area, and provide the theoretical and empirical results needed to specify and justify satellite systems using imaging radar sensors for global observations.

This plan was developed by the ERSAR Steering Committee based on the work of the ERSAR Working Groups. The structure of the ERSAR Committee is shown in Figure 1.

The ERSAR Program Definition Workshop Report is the foundation document for the Program Plan. This report is included as an appendix to provide easy reference to the background and rationale for the research tasks listed in this plan.

A coordinated research program is required because the present scarcity of research results are inadequate to demonstrate the measurement capabilities of active microwave remote sensing. It is apparent that the limited data acquisition and data processing facilities available are the primary constraints on the program. Consequently, the technology and support systems section of the program plan is the critical pacing element. Satisfactory implementation of these tasks schedules will govern the success of the overall effort.

NASA has concentrated on research and applications of visible/infrared remote sensing for over a decade. The ERSAR Committee recommends that consideration now be given to expanding into the microwave region of the electromagnetic spectrum to develop an adequate understanding of these data in preparation for their demonstration and use during this decade. This will require that an expanded coordinated active microwave research program be developed and implemented.

MICROWAVE REMOTE SENSING

The natural laws governing propagation and scattering of electromagnetic energy in the visible, infrared, and microwave regions are the same. The different responses observed are primarily due to the scale and electromagnetic properties of the object viewed relative to the wavelength of energy involved. For example, the texture of the surface of a leaf may be most significant when viewed with a visible sensor, whereas the geometry of the entire plant may be most significant when viewed with a microwave sensor.

The fundamental differences in the various remote sensing techniques are due to the source of the energy measured. For example, visible sensors measure reflected solar energy; thermal infrared sensors measure emitted heat energy; and active microwave sensors measure reflected coherent energy transmitted in a controlled manner from the sensor itself.

Active microwave measurements are sensitive to:

1. Dielectric properties
2. Volumetric composition
3. Surface roughness
4. Surface morphology
5. Geometry of man-made structures

The dielectric constant of water is high (50-80) relative to most natural substances (3-5), consequently, active microwave measurements are particularly sensitive to moisture content.

In addition to these measurement sensitivities, the fact that in active microwave remote sensing there is control of the coherence, amplitude, and direction of the transmitted energy provides this technique with the capability for improved measurement of the reflectivity, angle dependence, and polarization sensitive properties of objects/scenes. It also makes it essentially independent of sunlight conditions.

The usable microwave spectrum is very broad. Active microwave remote sensing is practical at wavelengths from 1.0 mm to 1.0 m. The spectral response of objects/scenes varies significantly over this range. For example, visible sensor data are sensitive to the top surface of exposed leaves of vegetation canopies, whereas microwave sensors may be sensitive to different components of the canopy depending on the illuminating wavelength. Short wavelength microwave sensors, e.g., 1.0mm, are also sensitive to the top leaves of the vegetation canopy. Medium wavelength microwave sensors, e.g., 1.0 cm, may be sensitive to the entire canopy volume, since this energy can penetrate into the canopy. Long wavelength microwave sensors, e.g., 1.0 m, may be virtually insensitive to the vegetation canopy and respond directly to the underlying soil. Similar spectral variations exist for active microwave sensing of snow, floating ice, clouds, and rain.

The characteristics of active microwave remotely sensed data cause these measurements to be highly sensitive to:

1. Composition of vegetation canopy volume, snowpack volume, sea ice volume.
2. Moisture in surface soil volume, snowpack volume, vegetation canopy volume.
3. Sizes of surface rocks, surface soil preparation, and roughness of natural surfaces.
4. Geometry of man-made structures and morphology of surface landscapes.
5. Land-water and water-ice boundaries.

RATIONALE AND JUSTIFICATION

The ERSAR Applications Working Group and the ERSAR Program Definition Working Group efforts concluded that:

1. Active microwave remote sensing appears to have significant potential for improving the capability to systematically monitor earth resources.

FIGURE 1. ERSAR COMMITTEE STRUCTURE

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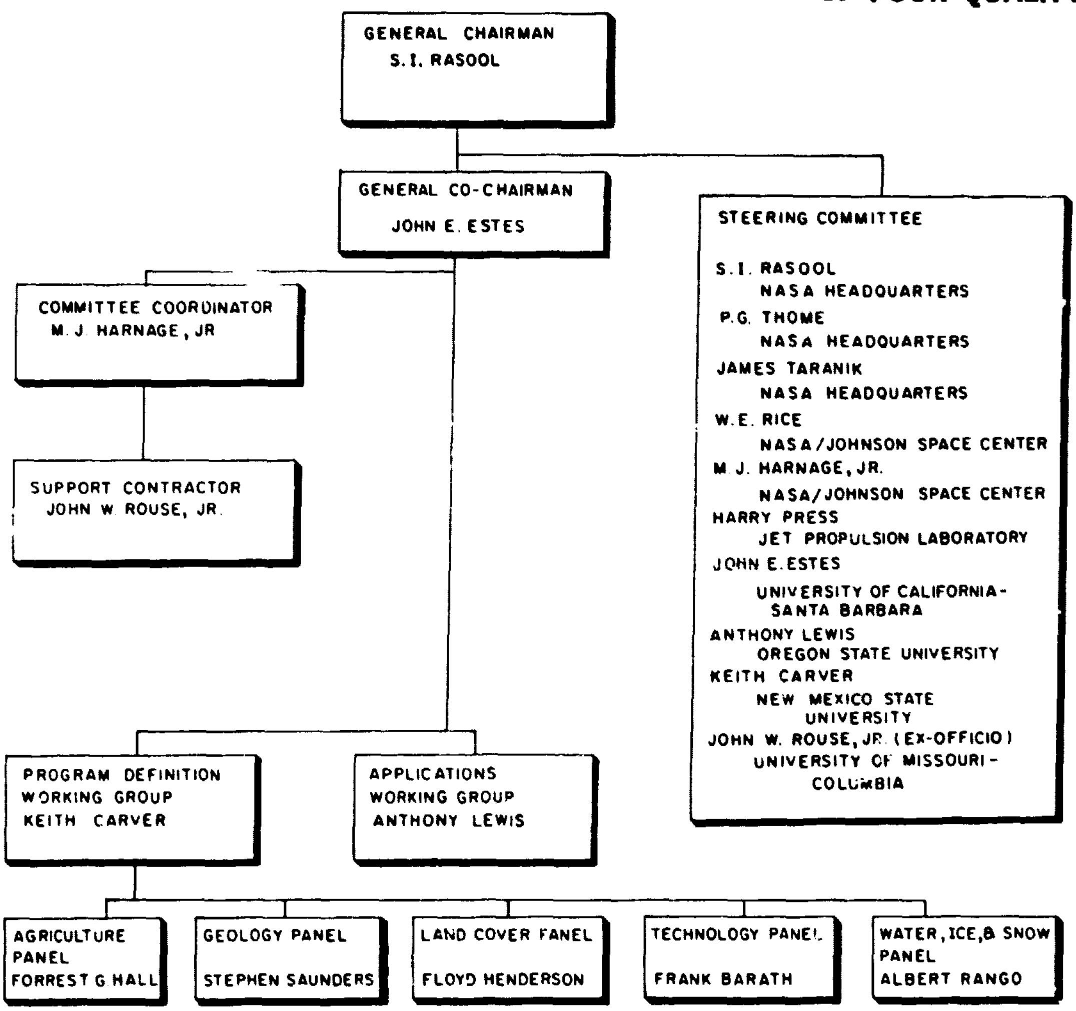

2. Present research results are inadequate to satisfactorily demonstrate the measurement capabilities of active microwave sensors for applications of primary interest.

These conclusions echoed those of seven other major independent studies of the capabilities of active microwave remote sensing which NASA has sponsored beginning with the Active Microwave Workshop in 1974. Each of these studies, involving a total of over 150 scientists and engineers, strongly recommended that NASA implement a coordinated active microwave research program.

In October 1977, a committee of the National Research Council (National Academy of Sciences) issued a report on their study of active microwave remote sensing. They also concluded that additional research was needed to document the potential of active microwave remote sensing for earth resource observations.

The ERSAR Applications Working Group reviewed the state of understanding of active microwave remote sensing and identified how the indicated measurements potential could satisfy specific information needs in selected applications. They considered applications in four topic areas: Geology; Agriculture; Land Cover; and Water, Ice, and Snow.

This study showed that there is a need for synoptic information other than that obtainable from visible/infrared sensor data. These needs include:

1. Cloud-free data,
2. Volumetric properties data e.g., canopies, ice, snow, soils,
3. Surface roughness data,
4. Electrical properties data,
5. Enhanced surface morphology and man-made structures data, and
6. Night-time data e.g., Arctic ice.

In the course of these analyses, it became clear that the potential of active microwave sensors as illustrated by theoretical or empirical evidence was attractive in several application areas. However, the severe lack of quantitative research background with active microwave sensors leaves many gaps in the understanding of the full capability of this sensing approach.

The ERSAR Working Groups determined that the apparent capabilities of active microwave sensors of

primary interest in the applications considered are:

1. Imaging in near all-weather, day and night conditions;
2. Sensitivity to vegetation and soil moisture conditions;
3. Sensitivity to vegetation canopy/timber variety and structure;
4. Controllable illumination direction;
5. Spectral information complementary and/or supplementary to Landsat data;
6. Enhancement of man-made structures;
7. Format compatible with Landsat and other remote sensor data;
8. Penetration into canopies, snow, ice, and soil; and
9. Sensitivity to surface roughness.

A review of the present NASA active microwave research effort by the ERSAR Program Definition Working Group showed that the level of activity was not commensurate with the potential of this sensing technique. In contrast, U.S. mineral and petroleum industries and several foreign countries have actively exploited the capabilities of airborne imaging radar sensors for exploration and resources inventorying. Some foreign governments, especially West Germany, are developing spaceborne imaging radar sensor systems and/or vigorous microwave remote sensing programs, such as in Japan and Canada. They are rapidly assuming a position of leadership in this field.

This program plan is designed to provide a coordinated research effort which will improve the state-of-knowledge in active microwave remote sensing to a level that will enable a clear understanding of the capabilities of this technique for earth resource observations. For this to be successful, it was first necessary to: (1) define the applications where such measurements are needed; (2) assess the potential of this sensing technique to eventually acquire the desired measurement; (3) determine the extent to which this measurement capability is presently understood; and (4) identify the specific research required to adequately demonstrate that a practical measurement capability exists. These tasks were the subject of the ERSAR workshops. The reports of the ERSAR Applications Workshop (Appendix A) and the ERSAR Program Definition Workshop (Appendix B) provide excellent discussions of these issues, and thoroughly detail the research needs.

PERSPECTIVE

In the process of identifying and describing the research tasks required in this program, the ERSAR Program Definition Working Group recognized that the understanding of the measurement capabilities of radar sensors was markedly different for different applications. For example, whereas there exists an enormous background of information on the use of radar image data for topographic information in support of geologic mapping, there has been virtually no research done in the area of rangeland mapping. The quantity and quality of information available in other application areas is highly variable. This situation required the Group to formulate research tasks which varied from exploratory, e.g., forest mapping, to verification testing, e.g., sea ice mapping.

In the design of each research task, the Group attempted to build on the existing base of empirical and/or theoretical knowledge. However, it is clear, as was stated by the ERSAR Applications Working Group, that in general, the quantitative understanding of the information content in active microwave sensor data is lacking. This is especially evident when attempting to justify specific operating wavelengths, polarizations, and incident angles. This is due to the fact that very little research in this topic area has been sponsored during the last decade.

Each research task is unique to the application of concern and the level of understanding which presently exists in that area. However, the general structure of the overall program includes three basic elements:

1. Modeling of radar signal responses to specific scenes or scene components, using empirical and/or theoretical techniques.
2. Verification of the models for an adequate range of scene (spatial) variables and radar system parameters.
3. Testing of the indicated measurement capabilities of radar sensors in realistic environments, by potential users of these data.

These elements encompass experimental activities which progress from basic measurements, such as provided by ground-based sensors or simple aircraft sensors, e.g., scatterometers, to area-extensive measurements with airborne imaging radar sensors, and finally to spaceborne SAR systems, such as SIR-A. However, the ERSAR Program Definition Working Group expressed some concern about the ability of airborne imaging radar sensors to provide the quality of data required to meet the research needs. The Agriculture Panel in particular, noted that:

> "Many characteristics of the aircraft SAR data are not representative of spacecraft data. The relatively large range of incident angles and the relative instability of the aircraft platform introduce distortions into the data sets which would not be present in spacecraft data. This was the experience with visible/infrared aircraft data. With the launch of ERTS (Landsat), a significant breakthrough was possible in the analysis of remote sensing data because the extremely difficult and intractible problems of aircraft scanner data disappeared at spacecraft altitudes. The panel feels that this experience will be repeated, and perhaps be even more difficult with airborne SAR data. While much can be learned with the aircraft platform, these data have ultimate, inherent limitations that can only be overcome through the use of well controlled experimental investigations from spacecraft."

The research program defined in this report is responsive to the needs identified by the ERSAR Working Groups. It is a significantly larger effort in active microwave remote sensing research than has ever been previously supported by NASA. It will require a major long-term commitment of resources, and most importantly, it will require attentive coordination by NASA and a solid interface with other federal agencies and with the scientific community.

MANAGEMENT PLAN

Successful implementation of the Active Microwave Remote Sensing Research Program requires that management devote considerable effort to the tasks of monitoring and coordinating the multitude of research activities in the program. Since the plan interrelates the various research tasks not only within disciplines, but across disciplines, it cannot be effectively accomplished without proper checks and balances. To assure effectiveness of these checks and balances and to maximize program results, a management structure must be adopted which ensures overall program visibility and concentrates responsibility and authority in key individuals so that program redirection can be given as necessary.

The ERSAR Committee recommends that the proposed research program be implemented through the Resource Observations Division, Office of Space and Terrestrial Applications, NASA Headquarters. The day-to-day activities within the program should be the responsibility of the appropriate applications or systems branches. A single point of contact should be established within this Division for the program. The overall program coordination and direction should be the responsibility of this person, who must have the status and authority to accomplish the job.

The Steering Committee membership should include:

Resource Observation Division Director or Representative (Chairman)

- Non-Renewable Resources Branch Representative
- Renewable Resources Branch Representative
- Systems Development Branch Representative

Environmental Observation Division Director or Representative
Oceans Branch Representative
Atmospheres Branch Representative
Communications Division Director or Representative
Chief Scientist, OSTA
Goddard Space Flight Center Representative
Johnson Space Center Representative
Jet Propulsion Laboratory Representative

The membership of the Steering Committee represents the major functional elements involved in implementing the program, and has the capability to continually review and evaluate the research activities and results, thereby facilitating appropriate inputs and assessments of potential program redirection.

It is recommended that the Steering Committee have resources (funds) available to them for a possible series of Evaluation Tasks designed to confirm, via independent review, that the experiments are properly structured; that the analyses are appropriate; and that the conclusions reached are reasonable relative to the supporting evidence.

During the workshop activities over the past few months it has become apparent that NASA does not presently have the systems capability for making the data measurements necessary to perform the proposed experiments. Many critical issues/problems must be resolved in the systems and technology area if research efforts are not to be unduly inhibited by a lack of fundamental information. In order for the program to be successfully implemented, concentrated efforts must be put into updating, refurbishing, calibrating and improving current acquisition systems and the accompanying data processing facilities. An organizational element is needed within NASA Headquarters to provide the focus and impetus necessary to accomplish these requirements. The formation of a new branch (Systems Development Branch) within the Resource Observation Division offers a viable solution for ensuring that the systems requirements are satisfied.

The actual methodology for accomplishing the research tasks, e.g., by Research and Technology Operating Plans (RTOP's) or Announcement Notices (AN's) should be at the discretion of each Branch, or a uniform approach can be established by the Divisions.

TECHNICAL PLAN

The objective of this planning effort is to identify those research tasks which must be performed in order to gain an adequate understanding of the measurement capabilities of active microwave imaging sensors. The information needs, i.e. the end objectives, were specified by the ERSAR Working Groups. The initial boundary conditions were established by the availability of support systems and personnel, and the existing FY1980 NASA research program. The funded microwave research and development programs are shown in Figure 2. Of these, the $2.1M Resource Observation Division program is most relevant. The program features 12 different projects. The primary funding emphasis is on soil moisture monitoring and geologic mapping. At present, there is almost no funding of microwave remote sensing projects in the vegetation canopies area; the area of prime importance is the ongoing visible/ infrared remote sensing research program. Likewise, there is minimal funding being devoted to improving the capability to acquire and process active microwave sensor data needed in support of the applications research activities.

The program plan for each emphasis area addresses specific research needs identified by the ERSAR Working Groups. These are summarized in the appropriate sections. The background and rationale for each is more fully developed in the workshop reports which appear in the appendices.

The research tasks, schedules, and resources requirements were prepared or reviewed by appropriate JSC, GSFC, or JPL personnel. The schedules provide general guidelines for the order of conduct of the various tasks. In all cases it is assumed that the technology and support systems effort is proceeding on the designated schedule. This schedule paces the entire effort since the availability of appropriate data acquisition and data processing facilities is critical to all of the experiment projects.

It is recognized that there is a limit to the ability of ground-based and aircraft active microwave sensor data to satisfactorily define the expected characteristics of future satillite sensor data. This was the case with visible/infrared sensor data prior to Landsat, and similar circumstances now exist in the active microwave remote sensing field. Consequently, existing Seasat SAR images and the forthcoming SIR-A images are expected to be extremely valuable to this program. It would be advantageous to this effort if similar satellite sensor data were available within the next few years.

The technical plan is structured to show the general research objectives and required research tasks in five topic areas:

1) Vegetation Canopies,
2) Surface Water,
3) Surface Morphology
4) Rocks and Soils,
5) Man-Made Structures.

These categories were selected because they provide comprehensive coverage of the primary application areas and they are unencumbered by terminology associated with ongoing programs in visible/infrared remote sensing.

VEGETATION CANOPIES

This emphasis area encompasses crop lands, forest lands, rangelands, wetlands, and vegetation associated with determination of underlying geology and watershed runoff characteristics. This research plan addresses the need to improve the understanding of active microwave sensor measurements of vegetation parameters such as species, condition, stage of growth, and distribution. The phased approach described in this section is structured in such a way as to compliment the major ongoing programs in visible/infrared remote sensing of vegetation canopies, e.g., AgRISTARS. A similar methodology is employed throughout, and common test sites are used where practical.

The initial stages of the research plan concentrate on developing fundamental electromagnetic interaction models based on theory and empirical data acquired from truck-based radar sensors and aircraft scatterometer sensors. A major effort is planned to develop the capability to preprocess, rectify, and interpret radar image data to achieve compatibility with visible/infrared (VIR) image data.

Although a variety of small measurement projects have been conducted in this general topic area in recent years, this research plan proposes the first systematic study of active microwave remote sensing of vegetation canopies. It is a particularly significant step in forest land and rangeland remote sensing, since neither of those important areas has been investigated in previous radar remote sensing projects.

Research Needs

Active microwave remote sensing appears to have the potential for sensing parameters related to vegetation type identification, areal extent, condition assessment, and stage of growth which may complement or supplement measurements obtained by other remote sensors. Of particular significance is the potential to distinguish among vegetation canopies having different canopy geometries and morphologies that change throughout the growing season; canopy water content and distribution; and canopy micro-environment (soil moisture, snow condition and amount, etc.). The potential of active microwave remote sensing for vegetation canopies is considerably enhanced by its inherent capability to obtain measurements frequently even in the presence of

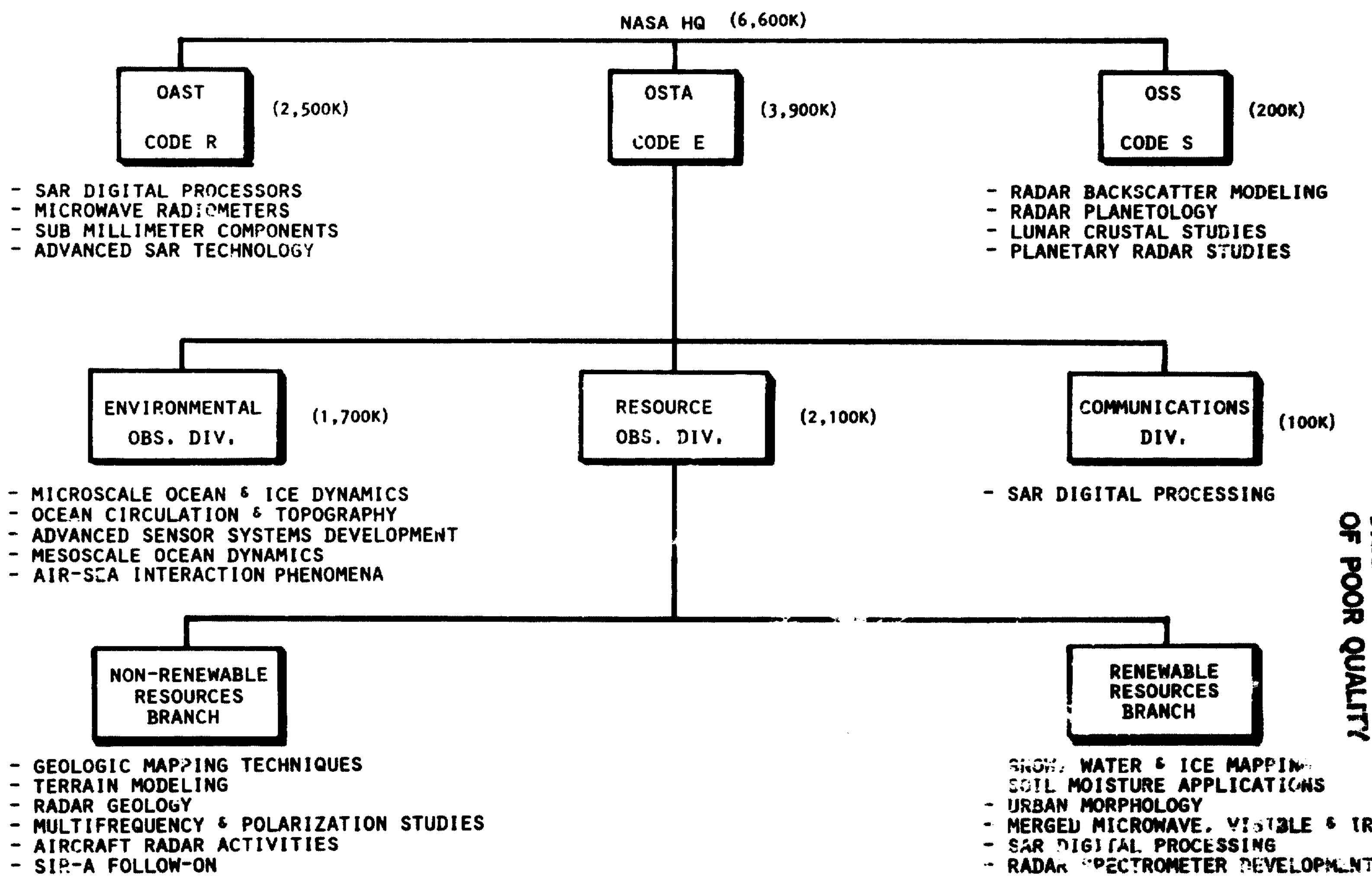

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FIGURE 2. FY 1980 NASA MICROWAVE RESEARCH AND DEVELOPMENT

cloud cover or under low sun angle conditions.

The applications in which this measurement potential may be of significance include:

1. Crop identification and areal measurement.
2. Crop condition assessment and yield estimation.
3. Crop development stage.
4. Forest vegetation identification and mapping.
5. Rangeland vegetation identification and mapping.
6. Watershed runoff characteristics due to vegetation.
7. Wetlands vegetation identification and mapping.
8. Vegetation distribution as related to underlying geology.

Empirical evidence exists to establish that several vegetation varieties can be distinguished in active microwave remotely sensed data. These studies have established that the use of radar data to augment Landsat data lost due to cloud cover can result in substantial improvements to classification accuracy. These studies also show that the addition of radar data to Landsat data can improve the accuracies achievable from cloud-free Landsat data of economically significant agricultural crops. Experiments have also shown that radar measurements are sensitive to yield-related parameters such as canopy water content and leaf area index of crop canopies. They are also sensitive to soil moisture, a potentially important parameter in yield estimation.

The empirical data base available to assess the measurement capability of active microwave sensors for crop identification and yield assessment is limited, but encouraging. The available data to support a comparable assessment of the measurement capability for forest vegetation and rangeland vegetation is at present too limited to support definitive statements on the relative measurement capability in these application areas. However, existing data do suggest that active microwave remote sensing data may enable mapping of forest stands by class and density, and of providing additional information on vegetation species in forested wetlands.

The ERSAR Working Groups conducted a careful review of the present state of understanding of active microwave remote sensing measurements. This provided a background for their determination of the specific research needs to establish the measurement capabilities of active microwave remote sensors relevant to vegetation canopies. They concluded that three major categories of research are required:

1. Theoretical, laboratory and field research to develop and to verify models and algorithms relating object/scenes classes and attributes to the characteristics in visible/infrared and active microwave multi-date data sets.

2. Research in large areas using candidate algorithms, image analysis, and pattern recognition investigations.

a. to establish relationships over extended areas between the characteristics of visible/infrared and active microwave multi-date data sets and the object/scene classes and attributes, and

b. to evaluate and to modify existing visible/infrared pattern recognition algorithms to analyze composite visible/infrared and active microwave data.

3. Research in large areas to investigate the data preprocessing and processing requirements to correct for sensor and atmospheric effects in active microwave data, to register active microwave image data to visible/infrared image data, or in any other way, to render these data sets mutually compatible for image analysis and pattern recognition.

Research Objectives

This program plan is oriented to achieve specific objectives in each application area within a five-year period. The general goals of the research effort are summarized below.

1. Establishment of a knowledge base characterizing the relationships between radar backscattering and vegetation canopy types and their attributes.

2. Assessment of the information content of SAR and composite SAR and visible/infrared image data for vegetation canopies, and determination of how this information can be utilized for various applications, i.e., agriculture, hydrology, land use, and geology.

3. Development of applications technology for processing and analysis of composite SAR and visible/infrared image data.

4. Specification of optimum radar system characteristics and mission parameters for spaceborne experiments involving vegetation canopy information.

5. Resolution of many of the critical technical issues inherent in using SAR data for vegetation canopy characterization.

Research Tasks

The first six (6) tasks address the first category of research listed under research needs, namely model and algorithm development. Tasks 7-11 relate to the second category of research, i.e., research in extended areas. The final four (4) tasks specify the research required in the third category listed, i.e., preprocessing and processing of active microwave data.

Task 1: Crop identification and Area Research

Develop baseline mathematical models to predict the radar backscattering of crop canopies and soil as functions of sensor configuration, frequency, and related crop canopy geometric and natural properties. Acquire wide-range multispectral, multi-temporal, and multi-date data from truck and helicopter platforms over small fields, e.g. 20mx80m, of wheat, barley, corn, soybeans, cotton, and rice at 10 day revisit intervals from emergence through harvest. Employ these data to produce simulations and models of visible/infrared and SAR image data over large areas. Develop labeling aids for large area pattern recognition and image analysis techniques for classification and area estimation of these crops.

Task 2: Crop Condition/Yield Research

Develop baseline mathematical models to predict backscattering by agricultural crops and fields as functions of crop condition and soil conditions. Develop mathematical models to predict yield given microenvironmental conditions and direct monitored crop moisture stress condition. Develop baseline models for root zone soil moisture estimation and subsequent effects on yield. Acquire small area (20m x 80m) wide range multispectral, multi-temporal, multi-configuration, multi-date data; process data; and prepare data for analysis with emphasis on wheat, barley, corn, soybeans, and cotton for estimation of root zone soil moisture. Develop and test algorithms to predict yield in crop areas using wide range multispectral data. Develop labeling aids for crop condition yield estimation and classification in large areas by pattern recognition and image analysis.

Task 3: Crop Stage of Development

Acquire radar data over crops during different growth stages. Develop baseline mathematical models for crop morphological change as detected by radar. Develop labeling aids for crop growth stage by pattern recognition.

Task 4: Forest Identification and Mapping

Refine or complete development of general model describing radar-signal scene-interaction phenomena using, where appropriate, results of truck-based and/or airborne experiments. Initiate development of specific simulation models as needed to support or explain specific phenomena measured from ground-based or airborne platforms. Acquire and analyze truck-based (or airborne) scatterometry data for use in more completely describing the fundamental relationships between radar and forested scenes. Predict ef-

fects of slope, understory vegetation, soil drainage, and other conditions as needed for development of comprehensive models for radar-forestry interactions.

Task 5: Rangeland Vegetation Identification Mapping

Review previous work related to radar measurements of rangeland, data manipulation, and data analysis. Begin acquisition and analysis of ground-based (or airborne) data to provide an indication of applications feasibility and indicate direction for subsequent research.

Task 6: Wetland Vegetation Identification and Mapping

Acquire small area (20m x 80m) wide- range multispectral, multi-temporal, multi-configuration, multi-date data; process data; and prepare data for analysis with emphasis on marsh, swamp, tidal flats, and open water in wetlands. Develop algorithms to predict wetlands classes using wide- range multispectral data. Develop labeling aids for wetlands classification in large areas by pattern recognition and image analysis.

Task 7: Large Area Crop Identification and Extent

Determine the sensitivity of radar data to plant/canopy characteristics. Determine the effects of background noise on the ability of radar to discriminate between crop types. Determine the optimum sensor parameters. Determine the best way to mix radar and visible/infrared data. Determine the added classification performance of radar and visible/infrared data compared to visible/infrared data alone.

Task 8: Large Area Crop Condition/Yield Research

Determine the sensitivity of radar data to plant/canopy characteristics related to crop stress and yield. Determine the ability of radar and visible/infrared data to predict crop stress and yield. Determine the improved performance that can be achieved by adding radar and visible/infrared data to weather data.

Task 9: Large Area Crop Stage Development

Determine plant/canopy factors which can be measured by radar sensors and determine the benefits of adding radar to visible/infrared data, plus weather data, for predicting crop stages. Determine sensitivity of radar data to crop stage development; effect of different incident angles; background and atmospheric effects; frequency of coverage required; and relationship between plant/canopy moisture and crop stage. Determine the benefits of including radar data with weather data to predict crop stage, and develop an appropriate temporal sampling strategy. Determine the benefits of including visible/infrared data with radar and weather data to predict crop stage and minimize atmospheric and background effects.

Task 10: Large Area Forest Vegetation Mapping

Determine the feasibility of using SAR data to map major forest land types for extent and extent change detection.

Task 11: Large Area Rangeland Mapping

Determine the feasibility of using SAR data to map rangeland vegetation. Process and analyze X-band SAR/VIR data obtained over Weld County, Colorado, grassland site during June 1979. Acquire multi-parameter airborne SAR and visible/infrared data multi-temporally over one or more rangeland areas exhibiting relatively large homogeneous conditions for vegetation type, condition, density, and maturity. Perform data processing and analysis to provide accuracy and reliability criteria for several combinations of SAR and VIR bands and configurations for the SAR data only, SAR and visible/infrared data, and visible/infrared data only cases.

Task 12: Rectification/Registration

Develop techniques for correcting image distortions caused by residual aircraft/spacecraft parameters, particularly yaw. Develop image formats (ground range, short range, stereo, etc) for agriculture, range, and forestry scenes. Develop registration and resampling techniques/algorithms which will allow spatial registration of multibeam, multi-frequency, multi-polarization, multi-date SAR data and visible/infrared data, including terrain relief for computer analysis/pattern recognition.

Task 13: Spatial Noise Reduction

Determine the extent of averaging needed for acceptable speckle for each agriculture application, and implement data preprocessing algorithms based on empirical/analytic models for each application within agriculture. The algorithms are to be developed through field experiments and/or analytical modeling.

Task 14: Incident Angle Effect Correction

Develop algorithms to reduce the effect of angle of incidence variations to provide nearly uniform images across the entire swath width.

Task 15: Software Development and Data Base Management

Initiate implementation of a rectification/registration/resampling software system to enable the building of merged data sets in pixel-registered form from multiple combinations of aircraft SAR, aircraft visible/infrared and Landsat visible/infrared data. Implement radar screening software system and approaches for spatial averaging of coherent noise/fading effects to improve SAR signal-to-noise characteristics. Incorporate angle of incidence correction of backscatter and finish registration/resampling system. Implement and test angle of incidence correction algorithms as developed under the data processing algorithm development. Increase throughput rate of merging aircraft and visible/infrared data and SAR data into registered resampled corrected multivariate data sets for classification. Incorporate modifications to rectification, registration, resampling, noise average, angle corrections as necessary from problems identified in multi-segment test of preprocessing and classification algorithms.

Schedule

A six-year program schedule for the research tasks in the vegetation canopies area is shown in Table 1. This schedule is highly dependent upon the orderly progression of the technology support activities.

Resources

The required resources to accomplish the proposed tasks are listed in Table 2.

SURFACE WATER

This emphasis area encompasses four separate research plans dealing with: 1) snowpack properties, 2) soil moisture monitoring, 3) watershed parameters, and 4) sea and glacier ice. The state of understanding in each area is significantly different. For example, monitoring floating ice with airborne radar sensors is a well-developed capability, where-

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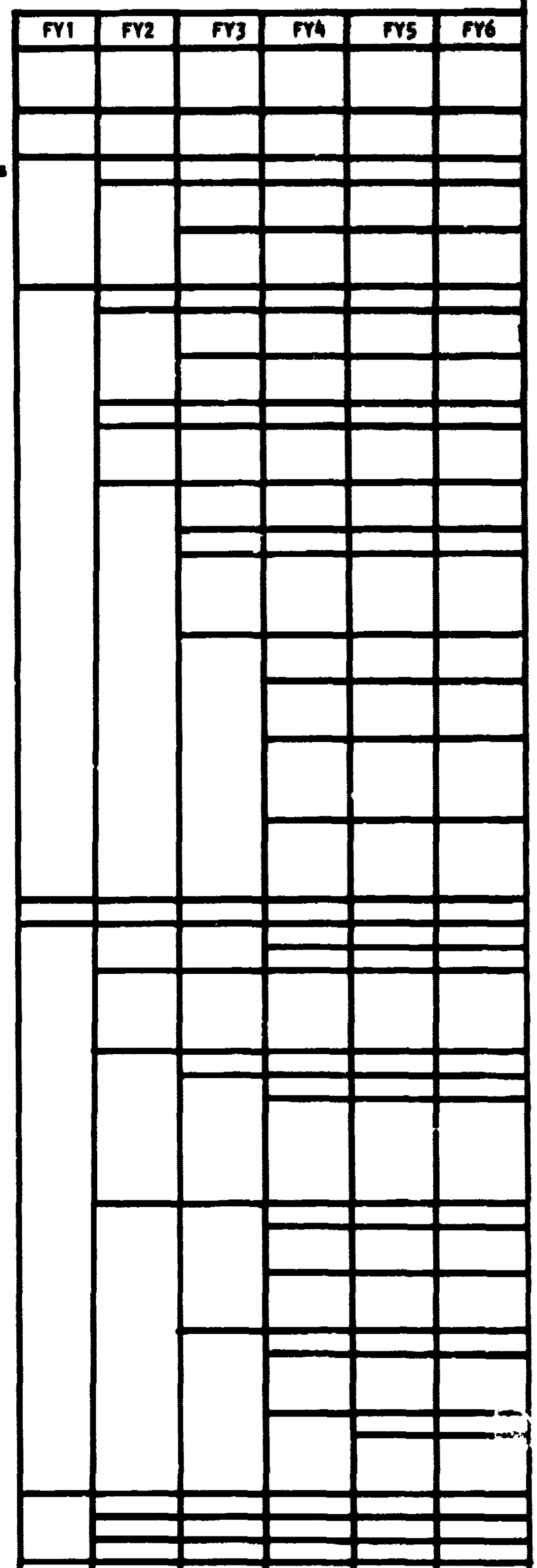
TABLE 1. GENERAL SCHEDULE OF VEGETATION CANOPIES RESEARCH



TASK 1: CROP IDENT. & AREA RES.
- -Baseline Math Model Development
- -Small Plot Multispectral Data Acquisition over Multiple Crop Conditions
- -Simulation Model Development for Large Areas for Crops
- -Labeling Aids Development for Pattern Recognition for Crops

TASK 2: CROP CONDITION/YIELD RES.
- -Baseline Math Model Development
- -Small Plot Multispectral Data Acquisition over Multiple Crop Conditions
- -Interpretation Algorithms Development by Inversion of Baseline Models
- -Yield Model Development
- -Root-Zone Soil Moisture Model Development

TASK 3: CROP STAGE OF DEVELOPMENT
- -Small Plot Multispectral Data Acquisition over Crops Having Different Stage of Development
- -Interpretation Algorithm Development
- -Labeling Aids Development for Pattern Recognition of Crop Stage of Development

TASK 4: FOREST IDENTIFICATION AND MAPPING
- -Small Plot Multispectral Data Acquisition over Forestland
- -Forest Model Development

TASK 5: RANGELAND VEGETATION IDENTIFICATION MAPPING
- -Small Plot Multispectral Data Acquisition over Rangeland and Analysis

TASK 6: WETLAND VEGETATION IDENTIFICATION AND MAPPING
- -Small Plot Multispectral Data Acquisition over Wetlands and Analysis

TASK 7: LARGE AREA CROP IDENT. AND EXTENT
- -Large Area Aircraft Data Using Pattern Recognition
- -Evaluation of Aircraft Data Using Pattern Recognition
- -Evaluation of Labeling Aids for Crop Identification
- -Evaluation of Large Area Data Using Statistical Pattern Recognition and Image Analysis

TASK 8: LARGE AREA CROP CONDITION/YIELD RESEARCH
- -Large Area Aircraft Data Acquisition over Cropland
- -Evaluation of Aircraft Data Using Pattern Recognition
- -Evaluation of Interpretative Algorithms with Large Area Data over Croplands for Crop Condition and Yield

TASK 9: LARGE AREA CROP STAGE DEVELOPMENT
- -Large Area Aircraft Data Acquisition over Cropland
- -Evaluation of Interpretative Algorithms with Large Area Data over Cropland
- -Evaluation of Labeling Aids

TASK 10: LARGE AREA FOREST VEGETATION MAPPING
- -Large Area Aircraft Data Acquisition over Forestland
- -Evaluation of Aircraft Data Using Pattern Recognition

TASK 11: LARGE AREA RANGELAND MAPPING
- -Large Area Aircraft Data Acquisition over Rangeland
- -Evaluation of Aircraft Data Using Pattern Recognition and Image Analysis Techniques

TASK 12: RECTIFICATION/REGISTRATION
TASK 13: SPATIAL NOISE REDUCTION
TASK 14: INCIDENT ANGLE EFFECT CORRECTION
TASK 15: SOFTWARE DEV. AND DATA BASE MANAGEMENT

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TABLE 2. RESOURCE REQUIREMENTS FOR VEGETATION CANOPIE. TASKS (FY81 DOLLARS) K$

TASK	FY1	FY2	FY3	FY4	FY5	FY6	TOTAL
1	50	300	400	550	550	200	2050
2	50	200	300	400	400	200	1550
3	--	100	150	150	100	50	550
4	--	--	100	200	220	150	670
5	--	--	---	90	120	150	360
6	--	--	---	50	100	120	270
7	50	350	350	500	500	200	1950
8	--	200	350	500	500	200	1750
9	--	200	350	500	500	200	1750
10	--	--	100	300	500	600	1500
11	--	--	---	90	200	300	590
12	50	350	350	200	100	100	1150
13	--	50	100	200	200	100	650
14	--	50	100	150	100	100	500
15	50	600	600	400	300	300	2250
TOTAL	250	2400	3250	4200	4390	2970	17540
AIRCRAFT COST	176	264	484	660	462	462	2508
TOTALS	426	2664	3734	4940	4852	3432	20048

as active microwave measurements of snow are sparce and poorly understood. Soil moisture monitoring is a major research effort at the present time, but flood mapping has received little attention. These circumstances require a wide range of program activities ranging from implementation of the well-developed soil moisture monitoring program plan previously developed under the direction of the Goddard Space Flight Center to initiating new experiments to refine the understanding of the characteristics of glacier ice.

The inherent characteristics of active microwave remote sensing are especially attractive for measurements of phenomena of interest in this topic area. The ability to penetrate into snow, moist soil, or ice, and to record useful data through cloud cover are particularly important for successful remote sensing in these applications. This research plan should lead to the determination of the feasibility of and the optimum system parameters of suitable orbital sensors.

Research Needs

The measurement potential of active microwave sensors is considered to be particularly significant for several categories of surface water. A key attribute of active microwave remote sensors of interest in these applications is the ability to penetrate into the subsurface volume. This is a necessary characteristic for effective remote sensing of snowpack properties, soil moisture, and floating ice. The extreme sensitivity of active microwave measurements to water causes this technique to be particularly useful in those applications where water is a principal parameter. These include:

1. Snowpack properties, including extent, depth, water equivalent, accumulation, snow melt, state, and state of underlying soil.
2. Soil moisture in subsurface (5-10 cm) layer and physical state of soil (frozen/unfrozen).
3. Flood extent and surface water boundaries in vegetated terrain through clouds.
4. Floating ice type, distribution, and dynamics on oceans, lakes, and rivers in all seasons.
5. Precipitation rates and extent over land.

Several experimental investigations have shown that radar data are sensitive to the physical characteristics of snowpack volumes, including equivalent water content. Long wavelength radar sensors appear to have the potential to measure the state of soil (frozen/unfrozen) beneath the snowpack. However, the existing data base is inadequate to support a quantitative assessment of the indicated measurement capability, nor is it adequate to support a definition of optimum sensor parameters.

Extensive experimentation with active microwave ground-based sensors have confirmed that radar data are responsive to soil moisture in the top 5-10 cm layer. These results have been confirmed with airborne radar scatterometer sensors, and a strong response to soil moisture variations has been seen in Seasat SAR measurements.

Analysis of radar images have shown the potential to delineate land-water boundaries for flood extent determination and wetland boundary mapping beneath vegetation canopies and trees. The potential to determine the physical state of soils (saturation, frozen/unfrozen) has also been indicated.

Considerable evidence exists to show the potential of radar data to map floating ice. Lake ice can be monitored operationally, e.g., ICEWARN. Sea ice can be classified by general type, i.e., first-year, multi-year, etc. There is presently sufficient understanding of this measurement capability to support the specification of system parameters for operational monitoring.

Theoretical studies suggest the potential of spaceborne radar sensors for recording precipitation rates and areal extent over land surfaces. This basic technique is now used operationally by ground-based and airborne weather radar systems. It is not known at this time whether or not this sensing technique is practical from orbitul altitudes.

Research Objectives

1. Achieve a theoretically-supported understanding of the microwave response to snow as a function of snow depth, liquid water content, surface roughness, and underlying soil state.
2. Verify the capability of radar sensors to monitor soil moisture.
   a. Understand [illegible] electromagnetic interactions involved.
   b. Develop [illegible] analytical models.
   c. Develop [illegible] er budget models.
   d. Assess the utility and feasibility of synoptic monitoring of soil moisture and physical state of soil.
3. Improve understanding of radar remote sensing of floating ice types, distribution, and dynamics.
   a. Advance understanding of geophysics and operational problem caused by floating ice.
   b. Demonstrate high velocity field calculations and ice hazard identification.
   c. Incorporate radar-derived information into current ice models.
   d. Document influence of snow cover, surface roughness, and several young ice types of radar measurements.
   e. Document capabilities of radar data for studies of floating ice.
4. Verify capabilities of radar data to delineate flood extent.
   a. Determine cartographic accuracy of radar-derived land-water boundaries.
   b. Establish optimum system parameters for flood and surface water mapping.

Research Tasks

Task 1: Snowpack Studies

Establish an experiment team to conduct an initial set of field spectra measurements under a variety of snow and climatological conditions. Model development will proceed in order to develop a thorough understanding and analytical description of radar backscatter from snow. Results from the initial study areas will be extended to a variety of study sites and snow conditions. Based on these data, the models and algorithms developed will be validated and where necessary, modified. A demonstration test with appropriate snow hydrology users will be conducted and will result in the definition of the optimum sensor system for snow measurements.

Task 2: Soil Moisture Experiments

Define and conduct an integrated and coordinated research effort to develop and refine active microwave remote sensing techniques which will determine spatial and temporal variations of soil moisture, and utilize soil moisture information in support of agricultural, water resources, and climate applications. This integrated effort will include the development of radiative transfer, soil profile moisture, and water budget models, employing microwave data, and a well coordinated field program of supporting truck and aircraft data acquisition.

Task 3: Watershed Parameters and Hydrology

Determine the active microwave capabilities for monitoring various watershed parameters useful for characterizing basin response and hydrological models. The monitoring capability will be extended to a variety of climate and vegetative types. A hydrological runoff model compatible with the remote sensing capabilities for watershed parameter monitoring will be developed and validated with field data. Flood mapping opportunities will be exploited when possible in the established study areas. Definition of optimum active microwave systems for hydrology, watershed parameter, and flood mapping will be a product of the experiment.

Task 4: Sea and Glacier Ice

Establish an experiment team to formulate and conduct a coordinated program in two major areas: sea ice and glaciers/ice sheets. In the sea ice study the objectives will be to determine processes active near the ice edge, determine the microwave properties of the central ice pack, and demonstrate feasibility of making high velocity ice field calculations. In the glacier and ice sheet study SAR data utility will be assessed for studies of glacier and ice sheet dynamics focusing on ice flow characteristics and coastal glaciers as navigational hazards. The optimum sensor systems for measuring ice processes will be completed.

Schedule

A five-year program schedule for the research tasks in the surface water area is shown in Table 3. This schedule is highly dependent upon the orderly progression of the technology support activities.

Resources

The required resources to accomplish the proposed tasks are listed in Table 4.

SURFACE MORPHOLOGY

The state of understanding of the application potential of active microwave image data to the analysis of surface morphology in this emphasis area is reasonably mature relative to other applications. The focus of this research plan is on developing the information extraction from radar images toward the objective of determining optimum sensor parameters for detection of the topographic configuration of land surfaces. The forthcoming SIR-A imaging radar experiment on the Space Shuttle will provide unique opportunities to verify measurement capabilities previously indicated by airborne data. Through detailed analysis of this surficial information, earth scientists cannot only make conclusions concerning a variety of surface related glacier phenomena (engineering, hydrology, etc.), but infer subsurface structure as well, which may be important in mineral exploration and other applications.

Research Needs

Imaging radar sensors have been used more extensively for measurements of surface morphology than for any other earth resources application. The reason for this is that the U.S. mineral and petroleum industries and several foreign governments have funded the acquisition and analysis of millions of square kilometers of high-quality airborne radar imagery. Consequently, it is known that radar remote sensing provides unique detection of the geometrical arrangement of topography because (1) the illumination, azimuth, and inclination angles are selectable; (2) unique detection of high-relief terrain in high latitudes; (3) unique detection of low-relief terrain in low latitudes; and (4) detection of topography in cloud-covered regions of the world.

As a result of these investigations, the relationships of radar image geometry to topography is reasonably well understood. However, there is presently a lack of adequate understanding of the optimum depression angles for best detection of topography in cloud-covered regions of the world.

The majority of the previous radar image analyses has been performed using airborne sensor data. This field of study is now at a stage where spaceborne data are required to support continued progress. The SIR-A system is expected to be particularly valuable for these studies. This system and future spaceborne imaging radar systems should be used in investigations which focus on a study of the geometry for optimum detection of both terrain in high and low relief areas and the geometry for optimum stereo viewing. There is a need to evaluate discrimination of rock and soil units using topography as detected by imaging radar systems, with special emphasis on drainage and landform patterns. There is a need to develop interpretive models to derive geological information from information on the geometry of surface topography as detected in radar image data.

Research Objectives

1. Development of a model which can be used with radar data for systematic analysis of terrain.
2. Determination of the types of geologic information which can be extracted from analysis of radar image data of topography.
3. Definition of specifications of optimum radar system for detection of topography.
4. Determination of procedures for optimum extraction of topographic information from stereoscopic radar data.

Research Tasks

Task 1: Radar Return Modeling

Develop theory and algorithms to model radar return for a variety of topographic settings. Simulate, in an image form, the effect of the radar observation geometry. Simulate stereo. Use digital topographic data as a starting data set.

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TABLE 3. SURFACE WATER RESEARCH TASKS SCHEDULE

TASK DESCRIPTION	FY1 1	FY2 2	FY3 3	FY4 4	FY5 5
TASK 1: SNOWPACK STUDIES					
ESTABLISH EXPERIMENT TEAM	—				
INITIATE FIELD SPECTRA MEAS.	—				
MODEL DEVELOPMENT	—	—	—		
EXTENDED AREA DATA ACQUISITION		—	—	—	
MODEL VALIDATION & MODIFICATION			—	—	—
DEMONSTRATION PROGRAM				—	—
OPTIMUM SYSTEM DEFINITION					—
TASK 2: SOIL MOISTURE EXPERIMENTS					
IMPLEMENT INTEGRATED PLAN	—	—	—	—	—
OPTIMUM SYSTEM DEFINITION					—
TASK 3: WATERSHED PARAMETERS AND HYDROLOGY					
INITIATE CAPABILITY STUDY		—			
EXTEND TO A VARIETY OF WATERSHEDS			—	—	
DEVELOP HYDROLOGICALLY COMPATIBLE MODEL		—	—		
VALIDATE MODEL			—	—	—
CONDUCT FLOOD MAPPING				—	
DEFINE HYDROLOGY, WATERSHED, AND FLOOD MAPPING SYSTEM DEF.					—
TASK 4: SEA AND GLACIER ICE					
ESTABLISH EXPERIMENT TEAM	—				
FORMULATE SEA ICE DEMONSTRATION		—			
START DEMONSTRATION PROJECT			—	—	
INITIATE FLOATING ICE EXPERIMENTS			—	—	
PLAN GLACIERS AND ICE SHEET EXP.			—		
INITIATE GLACIER AND ICE SHEET EXP.				—	—
OPTIMUM SYSTEM SPECIFICATION					—
TASK 5: PREPARE AND ISSUE (∇) ANNUAL AND FINAL REPORTS	—∇	—∇	—∇	—∇	—∇

Task 2: Effect of Radar Viewing Geometry on Mapping of Surface Texture and Topographic Features

Determine the effect of the observation geometry (incident and azimuth angles) on detection and identification of surface topographic features and textural features. Use radar data from orbital altitudes to assure homogeneous geometry.

Task 3: Radar Stereo Mapping

Assess and demonstrate the capability of the radar sensor to obtain useful stereo images. Conduct a parametric study for the use of stereo in image interpretation and topographic mapping. Use radar data from orbital altitudes.

Task 4: Land Forms and Drainage Analysis with Radar Data

Assess the capability of using radar for land form mapping and drainage network analysis. Trade off analysis of the different radar parameters effects. Use of data to infer the surface morphology and location of favorable sites for mineral and petroleum deposits.

Task 5: Radar Mapping of Surface and Near Surface Lineaments

Assess the capability of radar for mapping of surface and near surface lineaments. Determine the physical mechanisms which allow lineaments mapping and the radar

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configuration required for optimum detection. Compare to Landsat imaging and study the synergism of combining the two data sets. Use lineaments maps for inferring structural geology, possible mineral deposits and earthquake hazards.

Schedule

A five-year program schedule for the research tasks in the surface morphology area is shown in Table 5. This schedule is highly dependent upon the orderly progression of the technology support activities.

Resources

The required resources to accomplish the proposed tasks are listed in Table 6.

ROCKS AND SOILS

This emphasis area deals with the potential of active microwave sensors to differentiate surface characteristics based on roughness, and the subsequent information gained as to rock types and/or conditions. This information is

TABLE 4. SURFACE WATER RESOURCE REQUIREMENTS (FY81 DOLLARS) K$

TASK DESCRIPTION	FY 1	FY 2	FY 3	FY 4	FY 5	TOTAL
TASK 1: SNOWPACK STUDIES						3425
1.1 ESTABLISH EXPERIMENT TEAM	25					25
1.2 INITIATE FIELD SPECTRA MEAS.	200					200
1.3 MODEL DEVELOPMENT	150	200	250			600
1.4 EXTENDED AREA DATA ACQUISITION		250	300	500		1050
1.5 MODEL VALIDATION & MODIFICATION			100	350	350	800
1.6 DEMONSTRATION PROGRAM				300	350	650
1.7 OPTIMUM SYSTEM DEFINITION					100	100
TASK 2: SOIL MOISTURE EXPERIMENTS						5300
2.1 (ONLY ACTIVE MICROWAVE PORTION OF INTEGRATED PLAN)	500	800	1200	1500	1200	5200
2.2 OPTIMUM SYSTEM DEFINITION					100	100
TASK 3: WATERSHED PARAMETERS AND HYDROLOGY						2650
3.1 INITIATE CAPABILITY STUDY		200				200
3.2 EXTEND TO A VARIETY OF WATERSHEDS			350	400		750
3.3 DEVELOP HYDROLOGICALLY COMPATIBLE MODEL		250	350			600
3.4 VALIDATE MODEL			100	350	350	800
3.5 CONDUCT FLOOD MAPPING				200		200
3.6 DEFINE HYDROLOGY, WATERSHED, AND FLOOD MAPPING SYSTEM DEF.					100	100
TASK 4: SEA AND GLACIER ICE						2485
4.1 ESTABLISH EXPERIMENT	35					35
4.2 FORMULATE SEA ICE DEMONSTRATION		50				50
4.3 START DEMONSTRATION PROJECT			200	350		550
4.4 INITIATE FLOATING ICE EXPERIMENTS			500	500		1000
4.5 PLAN GLACIERS & ICE SHEET STUDY			50			50
4.6 INITIATE GLACIER & ICE SHEET EXP.				350	350	700
4.7 OPTIMUM SYSTEM SPECIFICATION					100	100
TASK 5: PREPARE AND ISSUE ANNUAL AND FINAL REPORTS	25	25	25	25	25	125
TOTALS	935	1775	3425	4825	3025	13985

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TABLE 5. SURFACE MORPHOLOGY RESEARCH TASKS SCHEDULE

		FY1	FY2	FY3	FY4	FY5
TASK 1:	RADAR RETURN MODELING					
TASK 2:	EFFECT OF RADAR VIEWING GEOMETRY ON MAPPING OF SURFACE TEXTURE AND TOPOGRAPHIC FEATURES					
TASK 3:	RADAR STEREO MAPPING					
TASK 4:	LAND FORMS AND DRAINAGE ANALYSIS WITH RADAR DATA					
TASK 5:	RADAR MAPPING OF SURFACE AND NEAR SURFACE LINEAMENTS					

TABLE 6. RESOURCE REQUIREMENTS FOR SURFACE MORPHOLOGY (FY81 DOLLARS) K$

		FY1	FY2	FY3	FY4	FY5	TOTAL
TASK 1:	RADAR RETURN MODELING	300	300				600
TASK 2:	EFFECT OF RADAR VIEWING GEOMETRY ON MAPPING OF SURFACE TEXTURE AND TOPOGRAPHIC FEATURES			600	800	800	2200
TASK 3:	RADAR STEREO MAPPING			300	500	700	1500
TASK 4:	LAND FORMS AND DRAINAGE ANALYSIS WITH RADAR DATA	200	300	300	600	500	1900
TASK 5:	RADAR MAPPING OF SURFACE AND NEAR SURFACE LINEAMENTS	250	350	450	600	500	2150
	TOTAL	750	950	1650	2500	2500	8350

important in both the engineering and mineral exploration applications of remotely sensed data. The research plan discussed below builds on promising work by USGS, and attempts to achieve an appropriate model to describe this measurement process. Examinations of radar image characterizations, such as texture calibration, wavelength, and polarization, are required to determine the feasibility of this remote sensing technique to contribute to the discrimination of rocks, unconsolidated rock weathering products, and soils.

Research Needs

The ERSAR workshops concluded that active microwave remote sensing data have the potential for unique detection of roughness of consolidated rock outcrops which can indicate grain size, degree of crystallinity, and porosity. These are important textural properties in rock classification. They also suggest a unique measurement potential for detection of size and angularity of unconsolidated rock weathering products (sand, gravel, cobbles, boulders, or bluffs) which is the basis for classification of these materials. There also appears to be some potential for detection of the moisture contained in consolidated rocks and rock weathering products. Contained moisture can indicate porosity and permeability of rock material.

These potential measurement capabilities are significant since:

1. An improved ability to discriminate materials at the surface would lead to the extraction of additional information on the presence of consolidated rock outcrops, unconsolidated rock weathering products, and soils.
2. An improved ability to discriminate water contained in materials would lead to the extraction of information on the condition of materials containing moisture.
3. The determination of the types of materials at the surface and the condition would be valuable in locating sources of aggregate and quarry rocks; pinpointing outcrops for field analysis; analyzing landslide potential; and determining suitable locations for highway rights-of-way.
4. An improved discrimination of rocks and unconsolidated rock weathering products and soils would lead to extraction of more geological information on geomorphic processes operating at the surface; mineral composition and texture stratigraphic sequences; and structural relationships.
5. Additional geological information leads to improved geological models of the evolution of the geologic framework; structural and stratigraphic processes; and concentration of minerals and hydrocarbons in the crust.
6. An improved discrimination of soils leads to improved understanding of their relationships to parent rock materials

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and their ability to support agriculture.

At present, considerable information exists concerning active microwave remote sensing of various types of unconsolidated rock weathering products. However, there is an inadequate understanding of the influence of different system parameters (frequency, polarization, etc.) on the information which can be extracted from radar data with respect to roughness of consolidated rock outcrops. Similarly, little is understood concerning the dielectric properties of consolidated rocks at microwave frequencies; the effects of contained water on the dielectric constant of consolidated rocks; or the relationships of soil chemistry to dielectric constant.

The research needs in this area include:

1. Theoretical, laboratory, and field research to determine the relationships between radar measurements and surface roughness at different frequencies, polarizations, and incident angles for different types of rocks and soil materials. This work should focus on the separability of rock outcrop, soils and unconsolidated rock weathering products such as silt and clay, sand, gravel, cobbles, and boulders. The research should include an evaluation of rock textural attributes expressed by roughness; size and angularity of unconsolidated rock weathering products; chemical composition of soils; and the effects of contained water. This effort should result in the development of data interpretation models which relate radar measurements to the type and condition of rock and soil materials.

2. Evaluate the discriminability of rock and soil materials over test sites in different physiographic environments. This research should include an evaluation of the effects of climate on contained moisture, and the relationships of moisture to discrimination of rocks and soils; of the effects of climate on rock outcrop weathering and its relationship to discrimination of rocks; and of the effects of minor amounts of vegetation (less than 30%) on discrimination of rocks and soils in different environments.

3. Develop interpretation models to derive geological information from information on the distribution of rocks and soils as determined from the analysis of active microwave data. This activity should include the development of models to relate materials discriminated by active microwave data through rock and soil forming processes; models to relate radar-discriminated rock units to lithology and stratigraphic sequence; and models to relate spatial variations and units discriminated in active microwave sensor data to geologic structure.

4. Develop interpretation models to derive agronomic information from information on the distribution of rocks and soils as determined from the analysis of active microwave image data. These models should address the relationship between radar-discriminated soil units and soil erosion, and the relationship between radar-discriminated soil units and vegetation production potential.

Research Objectives

1. Development of a set of theoretical models which relate radar backscatter to rocks, unconsolidated rock weathering products, and soils.

2. Determination of the types of agronomic and geologic information which can be extracted from SAR radar data.

3. Determination of digital analysis procedures for quantitative analysis of SAR data.

4. Define specifications of optimum radar system and mission parameters for discrimination of rocks and soils.

5. Define the software and system requirements for preprocessing of SAR data.

Research Tasks

Task 1: Microwave Interaction with Geologic Surfaces

Theoretical models development and experimental verification of the interaction of microwaves with natural surfaces. Study effect of surface roughness, slope and dielectric constant and subsurface inhomogeneities. Study and model the effect of the radar frequency, polarization and angle of incidence, and relationship of roughness and dielectric constant to rock type.

Task 2: Effect of Vegetation on the Radar Scattering from Geologic Surfaces

Modeling and field verification of radar scattering from different sites with a variety of surface cover, ranging from bare soil to full vegetation cover. Study effect of volume scattering from vegetation. Verify to what exte[illegible] radar signal penetrates the vegetation cover.

Task 3: Rock Discrimination Using Radar Image Texture

Develop and verify procedures to discriminate rock types based on image texture. Develop algorithms for automatic

TABLE 8. ROCKS AND SOILS RESEARCH TASKS SCHEDULE

TASK 1: MICROWAVE INTERACTION WITH GEOLOGIC SURFACES

TASK 2: EFFECT OF VEGETATION ON THE RADAR SCATTERING FROM GEOLOGIC SURFACES

TASK 3: ROCK DISCRIMINATION USING RADAR IMAGE TEXTURE

TASK 4: ROCK DISCRIMINATION FROM MULTI-SPECTRAL RADAR/LANDSAT IMAGES

TASK 5: RADAR IMAGE CALIBRATION AND QUALITY ASSESSMENT

TASK 6: RADAR DETECTION OF GEOBOTANICAL ANOMALIES

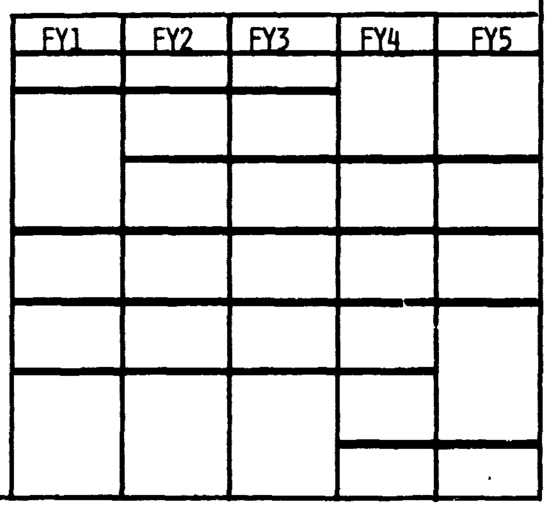

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TABLE 8. RESOURCE REQUIREMENTS FOR ROCKS AND SOILS (FY81 DOLLARS - K$)

		FY1	FY2	FY3	FY4	FY5	TOTAL
TASK 1:	MICROWAVE INTERACTION WITH GEOLOGIC SURFACES	200	300	200			700
TASK 2:	EFFECT OF VEGETATION ON THE RADAR SCATTERING FROM GEOLOGIC SURFACES		100	300	400	400	1200
TASK 3:	ROCK DISCRIMINATION USING RADAR IMAGE TEXTURE	300	400	400	500	500	2100
TASK 4:	ROCK DISCRIMINATION FROM MULTI-SPECTRAL RADAR/LANDSAT IMAGES	400	500	700	800	700	3100
TASK 5:	RADAR IMAGE QUALITY ASSESSMENT	100	200	200	100		600
TASK 6:	RADAR DETECTION OF GEOBOTANICAL ANOMALIES				200	400	600
	TOTALS	1000	1500	1800	2000	2000	8300

discrimination and quantitative classification.

Task 4: Rock Discrimination from Multispectral Radar/Landsat Images

Develop and verify procedures to discriminate surface rock types using the tonal information in radar images. Determine the role of using multispectral/multipolarization radar data in conjunction with visible/infrared data. Develop techniques for registration of images from different sensors.

Task 5. Radar Image Quality Assessment

Develop quantitative criteria for assessing the effects of different image parameters (number of looks, resolution, pixel size, etc.) on the interpretability of the image.

Task 6: Radar Detection of Geobotanical Anomalies

Determine the capability of the radar sensor, by itself or in conjunction with visible/infrared sensors, to detect botanical anomalies. Determine physical mechanisms which allow the detection. Relationship of botanical anomalies to surface geology.

Schedule

A five-year program schedule for the research tasks in the rocks and soils area is shown in Table 7. This schedule is highly dependent upon the orderly progression of the technology support activities.

Resources

The required resources to accomplish the proposed tasks are listed in Table 8.

MAN-MADE STRUCTURES

This emphasis area concentrates on those aspects of land cover analysis associated with the man-made environment. Such information can provide an important input in attempting to understand the complex factors which influence urban expansion as well as aiding in improving interurban land cover categorization accuracies. The research plan capitalizes on the indicated potential of active microwave sensor data to enhance man-made structures. It builds from the very promising ongoing studies using Seasat and aircraft SAR images. Development of applicable empirical models and suitable processing and classification procedures is incorporated in the research tasks with a primary emphasis on quantifying the cartographic properties and planimetric accuracy of radar images.

Research Needs

The ERSAR Program Definition Workshop Report contains a complete analysis of the types of studies required to properly define both the utility of synthetic aperture radars for the study of man-made structures associated with urban, near urban, and non-agricultural land uses, and also to provide the data and measurements necessary for designing a radar optimized for collecting data from such earth scenes. The highly regular and symmetrical geometries of many of these surfaces and the generally high-conductivity of surfaces associated with man-made structures, provide an enhancement of the radar signal reflected from these objects. Also, due to the spatial relationships between such classes of earth surfaces, they are often separable from one another. In many areas urbanization is encroaching onto surrounding rural lands. This encroachment produces a sharply contrasting class of land cover and associated man-made structures. This process is typified by an increase in the regularity of spacing of units and a decrease in the overall size of land units or parcels. This variation can be detected and measured by high revolution synthetic aperture radar sensors. This renders such systems viable candidates for monitoring the expansion of this urban fringe.

Man-made structure related research needs, as defined in the ERSAR Program Definition Workshop report are identified in five major areas:

1. Establishment of models to characterize the relationships between radar backscatter measurements and land cover elements and time in a variety of environments.
2. Improvement of the understanding of the effects of active microwave system parameters on the ability to accurately classify land cover;
3. Improvement of the understanding of the influence of environmental channes on radar backscatter measurements;

4. Development of a set of preprocessing and classification algorithms to take maximum advantage of the potentially unique character of active microwave data for land cover analysis (textural information, enhancement of man-made structures, etc.); and

5. Assessment of cartographic potentials of active microwave data with respect to the national map accuracy standards.

The first four tasks outlined above are considered as the top priorities in assessing the role of radar for land cover analysis particularly as they relate to man-made structures. Only after the texture and geometry contributions of radar have been established will the methods and problems of cartographic display be pertinent to land cover studies. However, the last task will be critical regardless of the nature of the earlier findings because much of the work in the other disciplines will require cartographic (map) display. Moreover, if radar data are to be integrated with and merged into (along with other sensor and ancillary data) geobased or georeferenced information systems for modeling and analysis, the techniques and procedures for registering such multi-dimensional data to a common base must be defined and addressed. For these reasons, the last task should be pursued independent of the results and conclusions derived from the first four.

At the present time, little information concerning the ability of synthetic aperture radar sensors to provide needed data on man-made structures in urban and near urban areas is available. This is due primarily to the lack of adequate data sets of such features coupled with sufficient and accurate simultaneous ground descriptions of the scenes. Thus, little can be convincingly stated concerning frequencies, look angles, polarizations, etc. for optimizing the extracting of pertinent man-made structure and related land cover data, as such, an integral and necessary part of the proposed research involves the collection of radar data from a variety of regional urban centers which are expanding and changing and exhibit a variety of man-made structure related land cover types; such data are to be studied by researchers in the regional area who are both familiar with the land use and unique environmental conditions of the area. It is proposed that this array of urban, suburban, rural scenes include Los Angeles, Seattle, Atlanta, Houston, Washington, D.C., Indianapolis, Denver and Miami, among others.

Level II land cover classification scheme (as defined in USGS Prof. Paper 965) is to be employed, and it is suggested that priority be given to the following elements:

1. residential
2. strip and clustered settlement
3. open areas and transition areas on the urban fringe
4. extractive activities
5. vegetated wetlands

These are the land cover components which are believed, because of the unique nature of the active microwave data, (moisture sensitivity, textural information) to be the ones in which such microwave data will be most beneficial with respect to discrimination from adjacent uses.

That land cover data are needed as a basis for information systems and decision-making for all aspects of resource management, conservation and allocation of activities at all levels of government and within the private sector as well, is a moot question. The acquisition of such information via intense ground surveys is exhaustively expensive, and the use of standard aerial surveys is often inadequate. The synoptic coverage provided by Landsat has expanded the horizons for such work but there are limitations on the types of man-related land use which may be extracted by using this (visible/ infrared) remote sensor. The addition of action microwave data to the presently available array of sensors is encouraged by the presently available and emerging research results. To verify the validity of such (often preliminary)

TABLE 9. MAN-MADE STRUCTURES RESEARCH TASKS SCHEDULE

	FY1	FY2	FY3	FY4	FY5
TASK 1: MODEL RADAR BACKSCATTER FROM MAN-MADE STRUCTURES					
-ESTABLISH SCIENCE TEAM					
-ACQUIRE DATA BASE					
-DEVELOP MODELS					
-TEST MODELS					
-SIMULATE SAR DATA					
TASK 2: PROCESSING AND CLASSIFICATION PROCEDURES FOR RADAR DATA					
-ASSESS PREPROCESSING AND CLASSIFICATION ALGORITHMS					
-PREPROCESS SAR DATA					
-TEST PREPROCESSING TECHNIQUES					
TASK 3: CARTOGRAPHIC PROPERTIES AND PLANIMETRIC ACCURACY OF RADAR DATA					
-ACQUIRE SEASAT SAR DATA					
-ANALYZE SAR IMAGE CHARACTERISTICS					
-DETERMINE CARTOGRAPHIC ERRORS					

TABLE 10. MAN-MADE STRUCTURES RESOURCE REQUIREMENTS (FY81 DOLLARS - K$)

	FY1	FY2	FY3	FY4	FY5	TOTAL
TASK 1: MODEL RADAR BACKSCATTER FROM MAN-MADE STRUCTURES	206	1299	748	427	610	3293
TASK 2: PROCESSING AND CLASSIFICATION PROCEDURES FOR RADAR DATA	300	1016	766	517	563	3522
TASK 3: CARTOGRAPHIC PROPERTIES AND PLANIMETRIC ACCURACY OF RADAR DATA	200	314	239	277	480	1618
TOTALS	706	2629	1753	1321	1653	8423

results as are available together with the definition of optimal radar systems for such work is the thrust of this research.

Research Tasks

Task 1: Model Radar Backscatter from Man-Made Structures

Develop empirical models which relate radar returns to specific classes of man-made structures in a variety of environmental settings.

Task 2: Processing and Classification Procedures for Radar Data

Identify preprocessing and/or classification algorithms which optimize identification of man-made structures when SAR data are used as input to pattern recognition procedures.

Task 3: Cartographic Properties and Planimetric Accuracy of Radar Data

Determine the map accuracy of SAR data over a given scene.

Schedule

A five-year program schedule for the research tasks in the man-made structures area is shown in Table 9. This schedule is highly dependent upon the orderly progression of the technology support activities.

Resources

The required resources to accomplish the proposed tasks are listed in Table 10.

TECHNOLOGY AND SUPPORT SYSTEMS

The ERSAR Program Definition Workshop Report contains a thorough analysis of the measurement systems required to conduct the research tasks specified in each application area. This analysis leaves no doubt that the major problem which must be resolved in order to implement this research program is that of acquiring usable experimental measurements. Existing sensors and data processing facilities are inadequate to support the proposed research.

The highest priority need in this program is to update, refurbish, calibrate, and improve the reliability of present truck-based and aircraft sensors and accompanying data processing facilities. The second highest priority needs is to increase the available data acquisition and processing capability, with immediate emphasis on truck-based sensor systems. The ERSAR Program Definition Workshop Report lists the specific systems required, and identifies an approach to accomplish these objectives. Major segments of this program must be delayed pending the completion of these two activities.

In general, the following tasks must be undertaken at the onset of the program:

1. Improve existing truck-based and aircraft sensor systems and data processing facilities to include calibration, reliable performance, and satisfactory data acquisition, recording, and throughput rates.

2. Develop the required additional truck-based and aircraft sensor systems and data processing facilities including new wavelength channels on selected, existing sensors; 1-18 GHz truck-based spectrometer; and helicopter-mounted scatterometer sensor.

3. Develop improved radar calibration techniques, image registration and preprocessing methods, radar stereo techniques, and image quality specifications.

4. Develop high-capacity SAR digital processor, and investigate advanced radar system concepts such as Multiple-Beam SAR and SCANSAR as possible alternatives to conventional SAR sensors for future satellite systems.

A review of the requirements for radar systems, data processing improvements and other active microwave technology developments clearly shows that certain of these systems development needs are shared by several of the applications areas and may be viewed as a common denominator to a viable program of active microwave research. Many of the radar sensors and data processing techniques are already partly or fully operational. However, a number of new frequencies, polarizations and platforms that are not now in the planning stages will be needed if all of the requested research needs are to be met.

The list provided in Table 11 is a summary of imaging and non-imaging radar systems. This table was compiled by the ERSAR Program Definitions Working Group. It is organized by the topic areas: agriculture, geology, land cover, and water/ice/snow, which overlap the five emphasis areas used in this plan.

The mere existence of these radar systems does not insure that the research needs outlined by the applications panels will be met. There are other crucial elements to meeting the research needs. For example:

1. Both image and non-image data must be carefully processed to provide final data products in a form which has clear quantitative meaning in terms of radar cross section and location. Furthermore, processing techniques must be developed which allow merging of data for multi-temporal,

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TABLE 11
APPLICATIONS REQUIREMENTS FOR TECHNOLOGY DEVELOPMENT

RESEARCH NEEDS	SPACECRAFT IMAGERY	AIRCRAFT IMAGERY	AIRCRAFT SCATTEROMETERS	OTHER A/C DATA	HELICOPTER SCATTEROMETERS	TRUCK SCATTEROMETERS	RADAR CALIBRATION REQUIRED	GEOGRAPHICAL REGISTRATION REQUIRED	DATA MERGING REQUIRED
AGRICULTURE									
1. Radar response from croplands	-	X-band SAR, VV, HH K_u-band SAR	X-bund + K_u-band, high angles	C-130 MSS/VIR	X-band Scatt.	X-band MAS data, 40°-60°, HH, VV	± 1dB	±25m	Digital Merging of C-130 MSS/VIR and X-band SAR images
2. Radar response from forests	-	X-band SAR, VV,HV,HH -------- C-band SAR VV,HV,HH	X-band + C-band 0°-60°, HH,HV,VV	C-130 MSS/VIR	X-band and C-band Scatt.	X-band and C-band HH,HV,VV	±1.8 dB (X-band) ±1.0 dB (C-band)	±20 m (X-band) ±50 m (C-band)	Man/optical merging of SAR and MSS/VIR data
3. Radar response from soil moisture	-	-	-	-	-	L-band and C-band 5°-20°	-	-	-
4. Radar response from rangeland vegetation	-	C-band and X-band SAR HH,VV	L-band, C-band, X-band, K_u-band HH,VV	C-130 MSS/VIR	-	L-band, C-band, X-band, K_u-band 10°-60° HH & VV	±1 dB	-	Multi-temporal merging of A/C SAR images
5. Radar response from soil salinity	-	L-band, and C-band SAR HH,HV	L-band, C-band, 15°-25°, HH,HV	C-130 MSS/VIR	-	L-band, C-band, 10°-40°, HH,HV	±2dB	±20m (saline seeps) ±100m (irri-gated agri.)	Multi-temporal merging of A/C SAR images
6. Image analysis and pattern recognition techniques	Landsat MSS & TM	X-band & K_u-band	-	-	-	-	±2dB	-	Multi-temporal merging of VIR and SAR images.
GEOLOGY									
1. Provide extensive land SAR data base	Large incidence angle, spaceborne SAR	-	-	-	-	-	-	-	-
2. Determine quant. relationship between geologic surface variables and radar system parameters	-	L-band, C-band, X-band SARs, dual-pol.	L-band, C-band, X-band 10°-60°	-	-	1-18GHz JPL Truck MAS	±1 dB relatives ±2.5 dB absolute	-	Merging of multi-frequency and multi-pol. SAR images

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TABLE 11
(continued)

RESEARCH NEEDS	SPACECRAFT IMAGERY	AIRCRAFT IMAGERY	AIRCRAFT SCATTEROMETERS	OTHER A/C DATA	HELICOPTER SCATTEROMETERS	TRUCK SCATTEROMETERS	RADAR CALIBRATION REQUIRED	GEOGRAPHICAL REGISTRATION REQUIRED	DATA MERGING REQUIRED
3. Determine utility of radar images for relation to surface and lithologic units, drainage pattern mapping, lineament mapping	SEASAT and SIR-A imagery Landsat	L-band and X-band SARs, HH,HV,VV	-	-	-	L-band and X-band 40°-60°, HH,HV,VV	-	-	SAR and Landsat merged data sets
LAND COVER									
1. Establish active microwave spectro. signature bank of urban to rural spectra	-	-	P,L,C, X and Ku bands, 10°-60° dual-pol.	-	1-18GHz, 10°-60°, dual-pol.	-	-	-	-
2. Investigate relation of environmental/ temporal land cover factors to radar system parameters	-	L-band, C-band, X-band SAR imagery dual-pol.	P,L,C, X and Ku bands, 10°-60° dual-pol.	C-130 MSS/VIR imagery to coincide with scatt. data	-	-	$\pm$1dB relative $\pm$2dB absolute	-	-
3. Improve preprocessing and classification procedures for radar data	-	-	-	-	-	-	$\pm$1dB relative	-	-
4. Establish cartographic properties of space-borne SAR data	SEASAT and SIR-A L-band imagery	-	-	-	-	-	-	Sufficient to meet National Map Accuracy Standards	Digital terrain model compensation to SAR imagery and merged multi-pass SAR images
WATER/ICE/SNOW									
1. Determine usefulness of radar data to assist in development of hydrologic models and estimation of soil wetness.	SEASAT L-band imagery	L-band, C-band, X-band SAR imagery	L-band C-band, X-band dual-pol.	-	-	1-12GHz MAS data, 10°-40° dual-pol.	-	-	-
2. Establish sensitivity of radar backscatter to snowpack conditions	SEASAT, SIR-A L-band imagery	L-band, C-band, X-band, K_u-band SAR imagery	L-band, C-band X-band K_u-band	-	-	1-18GHz MAS data, 10°-50° dual-pol.	$\pm$1dB relative for A/C imagery	-	-
3. Document capability of radar sensors to characterize floating ice. (See also results of ICEX parameter study.)	- Radar altimeter, 100-200 MHz needed on shuttle	L-band, X-band SAR imagery dual-pol.	L-band, C-band, X-band K_u-band dual-pol.	-	-	-	-	-	-

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TABLE 12

EXISTING SYSTEMS

Category	Organization	Frequency	Polarization	Angle of Incidence	Processing	Status
Truck-based	KU	1-18 GHz	Dual			Operational
	JSC	L, C, K	Dual	5° to 70°		Planned
	TAMU	X, L	Dual			Planned
	JPL	1-18 GHz	Dual		Digital	Under devel-opment
Helicopter	KU					Needs system integration support
Aircraft Scatterometers	JSC	P, L, C, K	Dual except K	5° to 60°	Digital	Operational
Aircraft Imaging Radars	JPL	L-band	Dual	0 to 60°	Optical/ Digital	Operational
	JSC	C, X	X dual, C,HH	X 10° to 60°	Optical	Operational
	ERIM	L, X		C 10° to 35°	Optical	Operational
	Goodyear	X			Optical	Operational
	JSC/JPL	1-10 GHz	Dual	10° to 60°	Digital	Under devel-opment
Shuttle Imaging Radar	JPL/JSC	L	HH	45°	Optical	Under devel-opment
Radar Sounder	JPL	100-200 MHz		0	Digital	Under devel-opment

multi-frequency and multi-polarization comparisons and composites. This requires careful attention to system calibration and registration, which in turn demands a substantial engineering development effort.

2. A second element is the recognition that for those high priority applications areas for which systems are designed, a very substantial investment must be made in data analysis and interpretation after the radar system has been shown to function properly. Unfortunately, in the past, this analysis/interpretation element has been poorly funded in relation to the sums spent on the radar system development so that the eventual or potential utility of the data for which the system was designed has often not been conclusively demonstrated.

3. A third element or philosophy implicit in most of the research needs is the assumption that truck and aircraft scatterometer data, when supplemented by aircraft imagery, can be used to provide a convincing case for the utility of spaceborne SAR data in meeting basic information needs. However, for any given specific proposed synoptic data need such as the measurement of snowpack water content, it must also be demonstrated that SAR system design parameters can be identified which will eventually lead to space imagery which can be used to measure snowpack wetness. In other words, after truck or aircraft data have established a sensitivity of radar data to a scene characteristic, it will then be necessary to define and verify spaceborne SAR parameters required for that application.

As is true for the analogous situations for visible/infrared imaging, there is a need common to almost all of the requirements for SAR imagery for preprocessing procedures which (a) reduce data dependence on look and incident angles, (b) eliminate atmospheric effects, (c) reduce speckle effects, (d) geometrically register imagery with standard projections, (e) eliminate topographically induced image-distortions at the higher frequencies, and (f) identify the effect of resampling after these preprocessing corrections. For aircraft scatterometer data, digital processing procedures must be used which correct for the aircraft flight parameters and which provide calibrated profiles of radar scattering coefficient versus a nadir time which can be easily related to ground location by correlation to photographic images. Finally, in addressing the widespread research need for merged imagery from a variety of sensors, there is a requirement to examine the feasibility of standard merged projections and to document the data processing tasks necessary to support this requirement.

Table 12 is a simplified summary of the radar systems which are now either in existence or which are under development. It is especially noteworthy that there are no operational helicopter-borne scatterometer systems in existence, and that most of the aircraft imagery is presently processed by optical techniques.

It is apparent that additions to the present complement of scatterometers and imaging radars are needed if all of the applications needs are to be met. A summary of needed technology developments, as derived from the previous discussion, is presented in Table 13, without ranking by priority in terms of research needs.

Truck-based Scatterometers - It is apparent that the present truck-based scatterometer systems cannot cope with either the data quantity or the timeliness required for meeting the research needs of the applications areas.

Truck-acquired measurements of the radar scattering coefficient are crucial to basic research needs in the areas

TABLE 13

NEEDED TECHNOLOGY DEVELOPMENTS
(not ranked by priority)*

Category	Organization	Frequency	Polarization	Angle of Incidence	Processing	Status
Truck-based	JSC	X-band	Dual	5^{o} to 70^{o}		Add to present system
	TAMU	X, C, L	Dual	"		"
	JPL	1-18 GHz	Dual	"		Under development
	University	1-18 GHz	Dual	"		New
Scatterometers	JSC	L-band		"		Replace outmoded L-band hardware
	JSC	X-band	Dual	"		New X-band system
	JSC	K	Cross	"		Replace outmoded K hardware, add dual polarization
Helicopters	JSC/KU	L-band and 1-18 GHz	Dual	"		Adaptation of KU system
Aircraft SAR	JSC	C-band	Cross	10^{o} to 60^{o}		Add to present
	JPL	L-band			Digital	Add to digital processing to present L-band
	JSC	K-band	Dual	"		New

*Priorities to be set by applications experiments teams

of crop land, soil moisture, rangeland vegetation, quantitative geology, hydrology, and snowpack investigations. The only fully operational truck-based 1-18 GHz spectrometer is the University of Kansas system. In order to take advantage of other truck systems which have partial capability, it is recommended that an additional X-band dual-polarized channel be added to the NASA/JSC system, and that both C and L-band channels be added to the Texas A & M truck system. The JPL 1-18 GHz truck-based spectrometer should be completed. A polarimeter capability should also be added to this system for geology studies. In view of the fact that these systems might still be unable to meet the stated research needs, an entirely new truck scatterometer university-based research facility may be required. This should be a 1-18 GHz spectrometer.

Aircraft-based Scatterometers - In order to answer the research needs for basic information on optimum frequencies for crop land, forest and geology remote sensing; it will be necessary to add an X-band dual-polarization scatterometer to the NASA/JSC C-130 aircraft and also to add cross-polarization capability to the present K-band scatterometer.

Helicopter-based Scatterometer - Basic research needs for fundamental data in the areas of forest and urban land cover remote sensing require scatterometer data over a wide angular range from a platform that can either hover or traverse over selected areas. In order to minimize total system costs, the scatterometer systems would be used as a strap-on package for use with locally available rental helicopters.

Aircraft SAR Imagers - The present NASA/JSC C-band SAR acquires data in the HH mode. Dual-polarization capability should be added to this WB-57 imager. Digital processing capability is needed for all aircraft SAR imagery, including the JPL L-band SAR which at present has limited digital processing capability. In order to answer fundamental questions on optimum frequencies (X versus K-bands) for radar remote sensing of crop lands, a new K-band aircraft-based SAR may be required. Since this would require a completely new system development which would be relatively costly, a recommendation for the engineering development of such a system would come only after a careful examination of X and K-band aircraft scatterometer data showed that there was justification.

In addition to the above specific radar systems, there are numerous fundamental technology efforts which are necessary in order to support the research needs of the applications areas. These can be broadly grouped into (1) system calibration and data processing and (2) advanced engineering systems. Of these two general areas, the most important task is the calibration and standardization of data from existing aircraft scatterometer and imaging radars. This means that reliable, calibrated and standardized data must be available from the present complement of sensors in order to make meaningful quantitative measurements. After demonstrating the potential of the present instrumentation to provide repeatable measurements, implementation

of advanced engineering systems concepts such as multi-frequency, multi-polarization, calibrated SAR sensors can proceed.

Technology Development Tasks

Task 1: Improvements to Present Radar Systems

A. Add an X-band dual-polarized scatterometer to the NASA/JSC truck system.
B. Add C and L-band dual-polarized scatterometer channels to the TAMU truck system.
C. Complete the JPL 1-18 GHz truck-borne active microwave spectrometer and add polarimeter capability.
D. Replace outmoded hardware on the NASA C-130 L-band scatterometer.
E. Replace outmoded hardware and add dual-polarization capability to the NASA C-130 K-band scatterometer.
F. Add digital processing capability to all aircraft imagers.
G. Add dual-polarization capability to the WB-57 C-band SAR.
H. Complete JPL radar sounder.

Task 2: Truck and Aircraft Radar Systems

A. Addition of dual-polarized K-band SAR to WB-57.
B. Addition of X-band dual-polarized scatterometer to C-130 aircraft and addition of on-board scatterometer data processing facility for all frequencies.
C. Adapt L-band and 1-18 GHz dual-polarized KU helicopter-borne strap-on scatterometers, and develop 1-18 GHz microwave active spectrometer.

Task 3: Data Processing and Calibration Techniques

A. Calibration and standardization of active microwave sensors.
B. SAR image quality/image registration and translation into system specifications.
C. Pixel preprocessing of SAR imagery.
D. Azimuth angle dependence of radar backscatter.

TABLE 14. TECHNOLOGY AND SUPPORT SYSTEMS TASK SCHEDULE

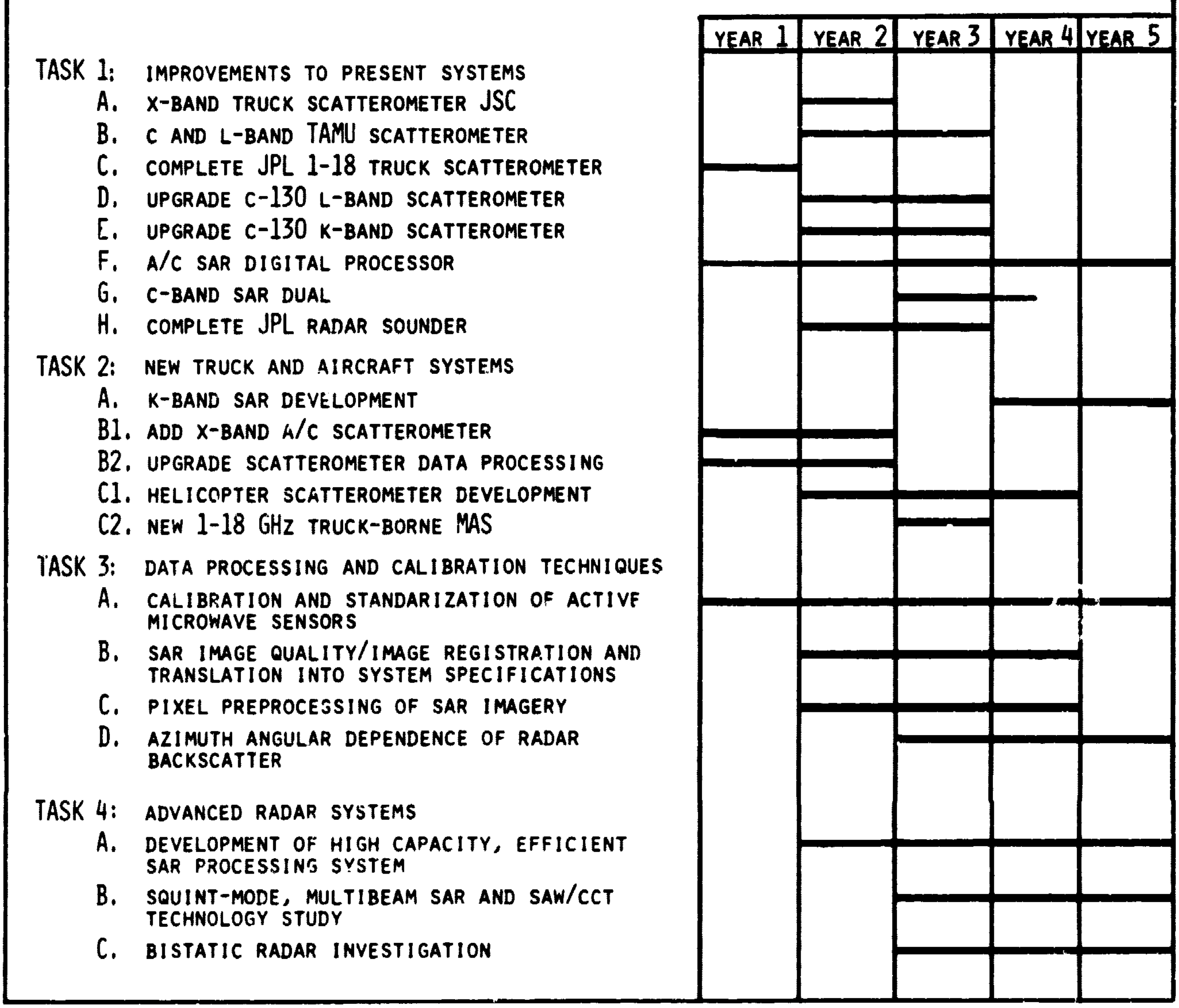

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TABLE 15. TECHNOLOGY & SUPPORT SYSTEMS FUNDING REQUIREMENTS (FY81 DOLLARS - K$)

	FY1	FY2	FY3	FY4	FY5	TOTAL
TASK 1: IMPROVEMENTS TO PRESENT SYSTEMS						
A. X-BAND ADDITION TO JSC TRUCK SCATTEROMETER		30				30
B. C- AND L-BAND ADDITION TO TAMU TRUCK SCATTEROMETER		100	75			175
C. COMPLETION OF JPL TRUCK SCATTEROMETER	100	300				400
D. UPGRADE C-130 L-BAND SCATTEROMETER		250	100			350
E. UPGRADE C-130 K-BAND SCATTEROMETER		250	100			350
F. UPGRADE A/C SAR DIGITAL PROCESSING	90	200	550	200	150	1190
G. DUAL-POLARIZATION ADDITION TO JSC C-BAND SAR			300	50		350
H. RADAR SOUNDER (100-200 MHZ)		200	200			400
TASK 2: NEW TRUCK AND AIRCRAFT SYSTEMS						
A. K-BAND AIRCRAFT SAR				300	500	800
B1. X-BAND AIRCRAFT SCATTEROMETER	300	100				350
B2. SCATTEROMETER REAL TIME DATA PROCESSING	60	60				120
C1. HELICOPTER SCATTERMOETER SYSTEM		50	250	150		450
C2. 1-18 GHZ TRUCK-BORNE SCATTERMOETER SYSTEM			300			300
TASK 3: DATA PROCESSING AND CALIBRATION TECHNIQUES						
A. CALIBRATION AND STANDARDIZATION OF ACTIVE MICROWAVE SENSORS	50	200	200	200	200	850
B. SAR IMAGE QUALITY/IMAGE REGISTRATION AND TRANSLATION INTO SYSTEM SPECIFICATIONS		100	300	300		700
C. PIXEL PREPROCESSING OF SAR IMAGERY		300	300	300		900
D. AZIMUTH ANGULAR DEPENDENCE OF RADAR BACKSCATTER			100	100	100	300
TASK 4: ADVANCED RADAR SYSTEMS						
A. DEVELOPMENT OF HIGH CAPACITY, EFFICIENT SAR PROCESSOR SYSTEM		450	1500	1000	500	3450
B. SQUINT-MODE, MULTI-BEAM SAR AND SAW/CCT TECHNOLOGY STUDY			100	100	100	300
C. BISTATIC RADAR INVESTIGATION			200	200	200	600
TOTALS	600	2590	4575	2900	1750	12415

Task 4. Advanced Radar Systems

A. Development of high capacity, efficient SAR processor system.

B. Squint-mode multi-beam SAR and SAW/CCT technology study.

C. Bistatic radar investigation.

Schedule

Table 14 identifies the task schedule required to support the applications research effort.

Resources

Table 15 lists the funding required for the technology development tasks.

PROGRAM EVALUATION PROJECTS

Attentive monitoring and coordination of the several simultaneous activities involved in this program is ex-

tremely important if the overall objective is to be achieved. In view of the size, cost, and complexity of this research effort, a series of independent evaluation projects should be conducted under the direct control of the Steering Committee. These studies will help ensure that the results are valid, and that the research tasks proposed for each subsequent year are appropriate to the respective objectives.

The evaluation tasks involves three related activities; 1) evaluation of models, 2) evaluation of measurement techniques, and 3) annual review of the program. Each evaluation task is expected to be a relatively small effort which might involve a single recognized expert reviewing the results of one research area, e.g. model of radar backscatter from snow. The objective of each evaluation task is to verify, via independent examinations, that the experiments are properly structured; that the analyses are appropriate; and that the conclusions reached are reasonable relative to the supporting evidence.

Research Tasks

Task 1: Model Evaluation

Evaluate theoretical and empirical models developed in the respective application tasks, e.g. soil moisture, water budget, etc., using alternate approaches, when applicable, and previous results reported in the relevant literature to verify the parametric dependences predicted in the subject models. Special attention should be given to confirming that a sound theoretical basis exists for all empirical models.

Task 2: Measurement Techniques Evaluation

Evaluate truck-based, airborne, and satellite sensor measurement techniques to confirm that adequate consideration has been given to all confusion factors, e.g. that fading statistics are properly averaged; that the calibration procedure is appropriate; that the precision of the measurements has been adequately determined; that the ground-truth and environmental data are sufficiently complete and accurate; that the data processing procedures are appropriate; and, in general, to establish the confidence level of the experimental data. This task also includes an evaluation of the sensor specifications for future truck-based, aircraft, and satellite sensors which result from the various application research programs to ensure that the proposed instruments can record the desired measurements.

Task 3: Program Review

Conduct an annual review of the technical results to assess and document progress and to provide information for program priorities and required funding levels for the next year. This review should use a symposium format with an accompanying workshop. A technical proceedings document should be prepared.

Task Schedule and Resources

The proposed schedule of evaluations and review is shown in Table 16. This schedule is highly dependent upon the progress made in the relevant application research programs. The estimated resource requirements are shown in Table 17. It is expected that these resources will fund independent studies by investigators not directly involved in the applications research programs.

CONCLUSION

The ERSAR Committee recommends that an active microwave remote sensing research program be implemented by the Office of Space and Terrestrial Applications beginning in FY 1981.

In developing this plan, it became obvious that the pace of the overall research program will be governed by the availability of useful data acquisition systems, and that the scope of the programs will be governed by the availability of qualified researchers.

This document provides guidelines for the process of transforming the several discipline specific research tasks developed by the ERSAR Program Definition Working Group into a viable Active Microwave Remote Sensing Research Program. This plan provides the basis for a detailed imple-

TABLE 16. PROGRAM EVALUATION TASKS SCHEDULE

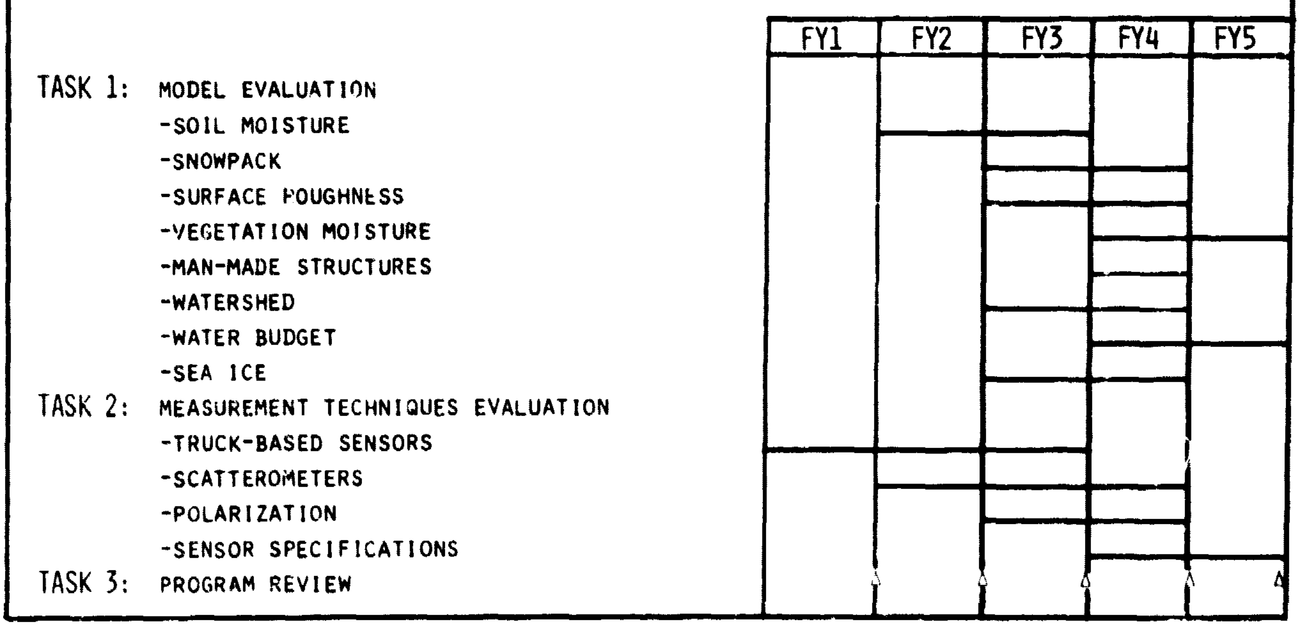

TABLE 17. PROGRAM EVALUATION RESOURCE REQUIREMENTS (FY81 DOLLARS - K$)

	FY1	FY2	FY3	FY4	FY5	TOTAL
TASK 1: MODEL EVALUATION						
-SOIL MOISTURE	20	30	30			80
-SNOWPACK			30	30		60
-SURFACE ROUGHNESS			20	20		40
-VEGETATION MOISTURE				40	40	80
-MAN-MADE STRUCTURES				30		30
-WATERSHED			25	25		50
-WATER BUDGET				35	35	70
-SEA ICE			30	30		60
TASK 2: MEASUREMENT TECHNIQUES EVALUATION						
-TRUCK-BASED SENSORS	40	40	40			120
-SCATTEROMETERS		50	40	30		120
-POLARIZATION			20	20		40
-SENSOR SPECIFICATIONS				50	50	100
TASK 3: PROGRAM REVIEW	50	50	50	50	50	250
TOTALS	110	170	285	360	175	1200

mentation plan.

This Program Plan focuses on several key issues:

1. Active microwave remote sensing appears to have significant potential for improving the capability to systematically monitor earth resources.

2. Present research results are inadequate to satisfactorily demonstrate the measurement capabilities of active microwave sensors for applications of primary interest.

3. A coordinated active microwave remote sensing research program is required to acquire sufficient understanding of this technique to assess its role in future earth observations missions.

4. Present data acquisition and data processing facilities are inadequate to support a viable active microwave remote sensing research program.

5. First priority must be given to acquiring data acquisition and data processing facilities capable of providing reliable active microwave sensor measurements.

6. The discipline-specific research tasks must be phased to optimize the limited sensor support systems, resources, and experienced personnel available.

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Appendix A

ERSAR

APPLICATIONS

working group

WORKSHOP REPORT

November 7-9, 1979

Houston, Texas

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Johnson Space Center
supported by
University of Missouri-Columbia

PREFACE

The ERSAR (Earth Resources Synthetic Aperture Radar) Applications Group Workshop held in Houston, Texas, November 7-9, 1979 was the first of a series of working sessions to develop an active microwave applications program plan. The program plan will aid NASA in establishing the value of active microwave sensor data in specific earth resources applications. The results of the ERSAR Applications Group Workshop will be used by the ERSAR Program Definition Group during their workshop January 23-25, 1980 in Pasadena, California. The product of these two workshops will form the basis for the program planning document.

This report presents the results of the Applications Group Workshop deliberations. The findings represent the judgment of 50 recognized experts in remote sensing applications. The working group was composed of four panels: Geology; Agriculture; Land Cover; and Water, Ice, and Snow. Each panel identified significant applications of remotely sensed data and showed how active microwave sensor measurements could contribute needed information.

The ERSAR Committee was formed to define the role of active microwave sensors in future earth resources programs. The committee is composed of a Steering Committee and various Working Groups. The ten-member Steering Committee includes representatives from NASA Headquarters, Johnson Space Center, Jet Propulsion Laboratory, and the Working Group Chairmen. The Working Groups are composed of recognized experts in the several topic areas of concern, i.e., the Applications Working Group and the Program Definition Working Group include users, researchers, and system specialists knowledgeable in remote sensing data applications and/or active microwave data acquisition and analysis techniques. S.I. Rasool, NASA Headquarters, is General Chairman of the ERSAR Committee; John E. Estes is General Co-Chairman. Anthony Lewis is Chairman of the Applications Working Group. Keith Carver is Chairman of the Program Definition Working Group. M. Jay Harnage, Johnson Space Center, is ERSAR Committee Coordinator responsible for conducting the working session with support from the University of Missouri-Columbia.

The ERSAR Committee, sponsored by the Johnson Space Center, continues a series of related activities initiated by JSC in 1974. These included the Active Microwave Workshop (1974), Active Microwave Study Group (1975), Active Microwave Users Workshop (1976), Microwave Remote Sensing Symposium/Workshop (1977), and the Shuttle Active Microwave Facility Review (1978).

ERSAR APPLICATIONS GROUP WORKSHOP REPORT

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LIST OF ACRONYMS AND ABBREVIATIONS

ERSAR	-	Earth Resources Synthetic Aperture Radar
NASA	-	National Aeronatuics and Space Administration
K_a-Band	-	Frequency band designation for 26.5 GHz to 40 GHz
X-Band	-	Frequency band designation for 8 GHz to 12.4 GHz
L-Band	-	Frequency band designation for 1 GHz to 2 GHz
C-Band	-	Frequency band designation for 4 GHz to 8 GHz
SAR	-	Synthetic Aperture Radar
CM	-	Centimeter
HH	-	Horizontal Transmit-Horizontal Receive
VV	-	Vertical Transmit-Horizontal Receive
USDA	-	United States Department of Agriculture
USDI	-	United States Department of Interior
IR	-	Infrared
FAO	-	Food and Agriculture Organization
USGS	-	United States Geological Survey
TM	-	Thematic Mapper
MSS	-	Multispectral Scanner
LAI	-	Leaf Area Index
GH z	-	10^9 Hertz
JSC	-	Johnson Space Center
MRS	-	Multispectral Resources Sampler
SIR	-	Spaceborne Imaging Radar
USFS	-	United States Forest Service
SCS	-	Soil Conservation Service
GEOS	-	Geostationary Earth Orbiting Satellite
DOE	-	Department of Energy
DOI	-	Department of Interior
NOAA	-	National Oceanic and Atmospheric Administration
WMO	-	World Meteorological Organization
CO_2	-	Carbon Dioxide
σ_o	-	Radar Scattering Coefficient
M	-	Meters
RPA	-	Resources Planning Act
λ	-	Wavelength

ERSAR COMMITTEE

The ERSAR (Earth Resources Synthetic Aperture Radar) Committee is a long-term activity initiated by NASA to guide the development of the applications which can benefit from active microwave sensor measurements. The overall objective is to establish the validity of active microwave sensor data for accomplishing earth resources applications when used independently or in conjunction with other types of data. The immediate objective is to develop and implement a detailed program plan to guide the research and development efforts in this field.

The ERSAR Committee consists of a Steering Committee and various working groups. The first phase of the Committee's effort involves two working groups: Applications and Program Definition. The ERSAR Committee structure is shown in Figure 1. The Applications Working Group participants are shown in Table 1.

The Applications Group Workshop will be followed by a Program Definition Group Workshop in Pasadena, California, January 23-25, 1980.

WORKSHOP OBJECTIVES

This workshop addressed two basic questions: (1) What significant earth resources applications can be better addressed if active microwave sensor data were available to supplement existing or proposed data sources, and (2) Why or in what way do active microwave sensor data provide the desired additional information?

Specifically, the Applications Group Workshop undertook four tasks: (1) Identify high priority user data/information needs which can potentially be met by remotely sensed data; (2) Specify user needs that potentially could only or best be met with active microwave data, and those needs that could best be met in combination with other types of data; (3) Document the state of current understanding as to the information (type, accuracy, etc.) that can be extracted from active microwave remote sensing data; and (4) Identify significant gaps that should be filled by a well-developed, coordinated research program.

The Workshop was structured to provide the participants with a summary of applications of remotely sensed data and recent developments in active microwave remote sensing. Each panel expanded on this to perform the assigned tasks. An agenda for the Applications Group Workshop is appended to this report.

SUMMARY

The initial objective of the ERSAR Applications Workshop was to identify those applications of remotely sensed data that could be better addressed by adding active microwave data to the existing or anticipated data sources. This was accomplished by identifying the proven capabilities of imaging radar sensors and comparing them to the information needs in each of four discipline areas: geology; agriculture, land cover; and water, ice, and snow.

In the course of these analyses, it become clear that the potential of active microwave sensors as illustrated by theoretical or empirical evidence was attractive in several application areas. However, the severe lack of quantitative research background with active microwave sensors leaves many gaps in the understanding of the full capability of this sensing approach. The Working Group identified some of the foremost research results needed to resolve key questions about the ultimate utility of active microwave sensors.

The apparent capabilities of active microwave sensors of primary interest in the applications considered are:

1. imaging in near all-weather, day and night conditions;
2. sensitivity to vegetation and soil moisture conditions;
3. sensitivity to vegetation canopy/timber variety and structure;
4. controllable illumination direction;
5. spectral information complementary and/or supplementary to Landsat data;
6. high resolution imaging independent of distance to scene;
7. enhancement of man-made structures;
8. format compatible with Landsat data; and
9. unique data source for select applications, e.g., floating ice, soil moisture, snow water equivalent, tropical forest resources.

Among these, the capability of greatest interest, according to this Working Group, is that of high resolution imaging through clouds. The Group stressed that a capability to supplement Landsat data in cloud-covered regions would fill a major information need. Timeliness of data acquisition is considered a key to improving the effectiveness of remotely sensed data for several applications involving dynamic phenomena, e.g., vegetation development, soil moisture, floating ice movement, snow melt, disasters.

The ability of active microwave sensors to acquire information through clouds is inherent; however, adequate evidence is lacking as to the value of such information to those applications in need of cloud-free data. Experiments have shown radar to be sensitive to vegetation moisture and structure. This suggests that crop type and growth stage can be identified, but this capability is yet to be fully substantiated. Experiments have shown that radar is very sensitive to soil moisture content in the top 5-15 cm of soil, but the data are too limited at present to define an operational approach to synoptic monitoring. Experiments have shown that radar is sensitive to the water equivalent in snow, but the data base is inadequate to establish the ultimate ability of this potentially important characteristic.

In general, the quantitative understanding of the information content in active microwave sensor data is lacking. This is especially evident when attempting to justify specific operating wavelengths, polarizations, and incident angles. The fact is that very little research in this topic area has been sponsored during the last decade.

In contrast to this situation, the use of radar image data in qualitative analyses, particularly for geologic applications, is well developed. The mineral and petroleum industries and several foreign governments have invested substantial sums of money to acquire and analyze airborne radar image data. The value of such information has been demonstrated repeatedly in economically significant exploration and resources survey activities.

The high quality mapping capability of imaging radar sensors has been employed enough to give confidence in this approach, and to lend encouragement to those exploring the land cover applications area, for example. However, the added value of radar image data to existing or anticipated visible/infrared data to meet the information needs in land cover analyses is yet to be adequately determined. The recently demonstrated capability of merging radar and Landsat data both pictorially and in automatic classification schemes is promising as a means to satisfy several land cover and other applications information needs. This, too, is yet to be examined in sufficient detail to clearly demonstrate the potential information gain, although the preliminary work on vegetation identification using combined radar/Landsat data sets is very encouraging.

The Working Group identified several specific research needs based on their analysis of the present state of knowledge and the information needs in each of several relevant applications. Of particular significance among these are:

Geology

1. Establish the dependence of radar backscatter on surface roughness and dielectric properties of natural bare and vegetated terrains with special emphasis on optimum wavelength, polarizations, and incident angle for effective

FIGURE 1. ERSAR COMMITTEE STRUCTURE

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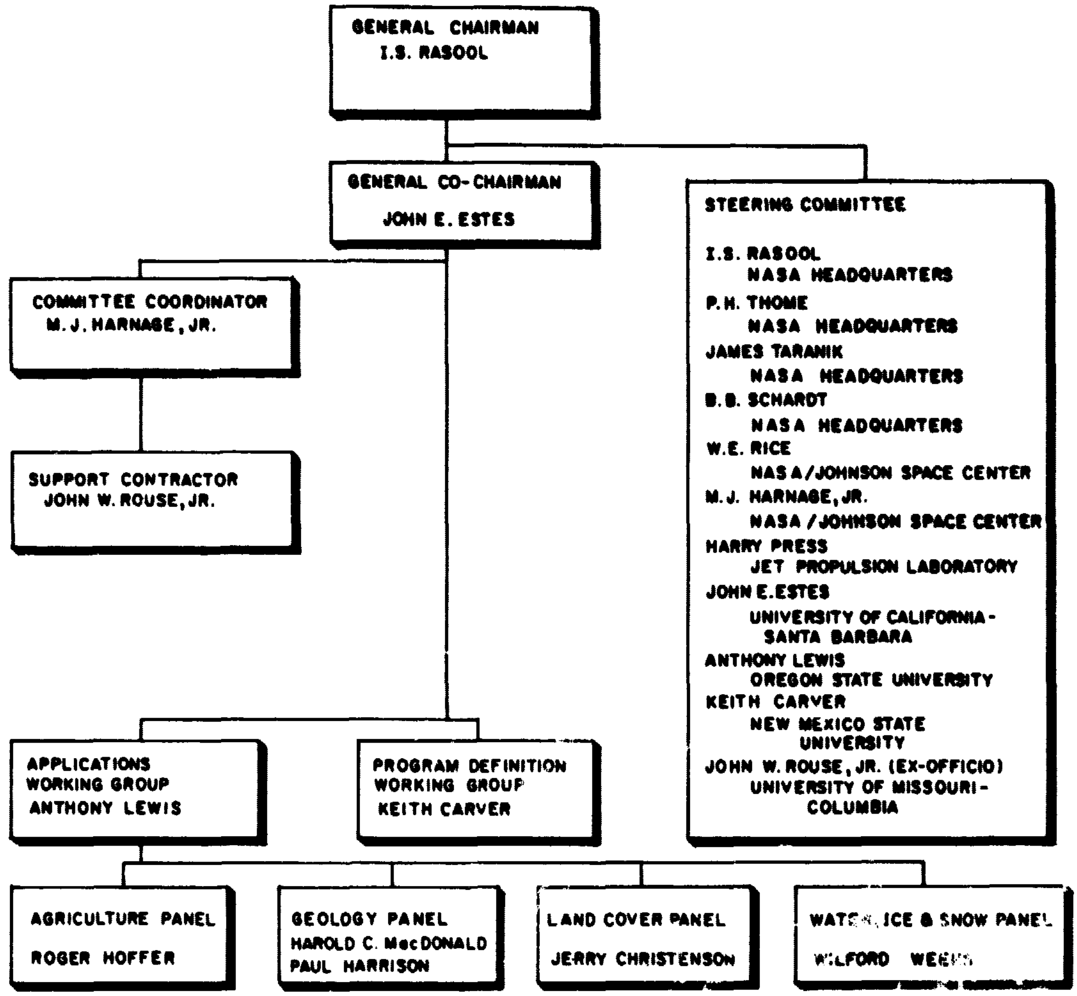

measurements.

2. Establish the utility of stereoscopic radar images as aids to geologic interpretation and measurement of vertical relief.

3. Determine the value of repetitive (seasonal) synoptic coverage for geologic applications.

4. Document the potential of orbital image data for environmental monitoring, e.g., oil seeps and spills.

Agriculture

1. Establish the sensitivity of radar backscatter to complex vegetation canopies with special attention to the following crops: corn, sorghum, soybeans, wheat, cotton, sunflowers, and rice; and the following radar parameters: wavelength, polarization, resolution, and incident angle.

2. Establish the value of radar image data as an additional spectral channel to Landsat for improved crop discrimination in a variety of environments.

3. Establish the effect on radar backscatter of soil moisture variations in a variety of environments.

4. Define the required radar image characteristics for effective vegetation-related measurements, with special attention to resolution, calibration accuracy, registration, speckle effects, and dynamic range.

5. Document the potential of radar sensor measurements of timber species, timber volume, and tree vigor as affected by disease and insect infestation.

6. Determine the capability of radar sensing as an aid to determining rangeland productivity and trends.

Land Cover

1. Document the potential of radar image data used independently and/or in conjunction with visible/infrared image data for improving urban area boundary delineation and urban landcover classification accuracy in both manual and automatic mapping and thematic classification. Include an analysis of radar parameters such as resolution, azimuthal look direction, wavelength, polarization, and incident angle.

2. Establish the value of radar/Landsat composite data for improved land cover/land resources mapping with emphasis on multifrequency, multipolarization radar data.

Water, Ice, and Snow

1. Document the capabilities of radar sensors to accurately measure the types, velocities, strains, and strain rates of floating ice, with special emphasis on the marginal ice zone of the Arctic ice pack.

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2. Establish the sensitivity of radar backscatter to snowpack characteristics, especially wetness, and to underlying surface conditions. Include analyses of the effect of wavelengths, polarization, and incident angle.

3. Determine the capability of radar sensor data to assist in the development of hydrologic models at varying levels of spatial resolution with special emphasis on the measurement of soil wetness.

PANEL REPORTS

The reports of the four panels presented in this section are essentially reformatted versions of the original material prepared during the three-day workshop. A copy of the final draft was distributed to all panel chairmen for approval prior to release of this document.

The panel reports are organized to first provide an overview of the present state of knowledge in active microwave data utilization and/or interpretation. This is followed by a section identifying those applications which can benefit from active microwave and other sensor measurements. The potential of these data to serve the information needs of the applications is then discussed. This is followed by a summary of the research needed to validate the indicated potential. Finally, the recommendations of the panel are listed.

GEOLOGY

STATE OF KNOWLEDGE

There are two types of information in a radar image. There are spatial, qualitative relationships between features in a scene that can be interpreted in terms of geologic structures or of landforms, and there is quantitative backscatter information that characterizes the scattering elements in each resolution cell.

The state of knowledge in the qualitative use of radar imagery for the specific application areas is well developed. This is evidenced by over 10 years of operational performance by commercial contractors for numerous projects utilizing the higher frequency systems (Ka & X-band). With

Table I. APPLICATIONS WORKING GROUP PARTICIPANTS

AGRICULTURE PANEL

Roger Hoffer, Chairman
Purdue University
Andrew Blanchard
Texas A & M University
Forrest G. Hall
NASA/Johnson Space Center
Roy Hatch
USDA/ESCS
Phillip Jackson
Environmental Research Institute of Michigan
Chris Johannsen
University of Missouri-Columbia
Robert B. MacDonald
NASA/Johnson Space Center
John Nieber
Texas A & M University
Richard Phelps
Anderson Clayton & Company
Paul Tueller
University of Nevada-Reno
Fawwaz Ulaby
University of Kansas

GEOLOGY PANEL

Harold C. MacDonald, Co-Chairman
University of Arkansas
G. Bryan Bailey
EROS Data Center
P. J. Cannon
University of Alaska
Michael B. Duke
NASA/Johnson Space Center
Anthony England
NASA/Johnson Space Center
Ronald Gelnett
MARS, Inc.
Paul Harrison, Co-Chairman
Cities Service Corporation
Harold Masursky
USGS/VIOR Team
William C. Ramsey-Palmer
Consultant
Stephen Saunders
Jet Propulsion Laboratory
Barry Seigal
EBASCO
Harry E. Stewart
Jet Propulsion Laboratory
Kathy Sullivan
NASA/Johnson Space Center

LAND COVER PANEL

Jerrold Christenson, Chairman
Environmental Systems Research Institute
M. Leonard Bryan
Jet Propulsion Laboratory
Nevin A. Bryant
Jet Propulsion Laboratory
John Place
U.S.G.S.
Ronald Shelton
Michigan State University
O. G. Smith
NASA/Johnson Space Center
Chih Tseng Wu
NASA/National Space Technology Laboratory

WATER, SNOW, AND ICE PANEL

Wilford Weeks, Chairman
U.S. Army CRREL
Kenneth Demel
NASA/Johnson Space Center
Ted Engman
USDA/Hydrology Laboratory
Kumar Krishen
NASA/Johnson Space Center
Albert Rango
NASA/Goddard Space Flight Center
Robert Shubenski
Water Resources Engineers
Allen Thorndike
Polar Research Center
William P. Waite
University of Arkansas

this history, the geologist is already well prepared to extract geologic information from the spatial relationships in a radar image. Enough is known about these relationships to justify the acquisition of high quality radar data for large portions of the earth's land surface. The existing user communities would benefit greatly from the availability of such a uniform data set, and through their use of the data, a clearer perception of the desirable characteristics of the next generation of radar systems will emerge. That is, enough is now known to justify and fully utilize good quality radar imagery of large regions of the earth, and perhaps the best way to further radar remote sensing in geology is to provide these large data bases to the user community.

However, the level of understanding of the quantitative information in active microwave sensor data is presently inadequate. There is, without doubt, much more information in radar backscatter data than is presently understood or even anticipated.

The sub-resolution cell information of surface roughness supplies the amplitude information which is absolutely necessary in order to quantify the desired results. This step advances the geologist from the structure analysis and landform recognition phase to an understanding of the surface materials. The surface materials are a major part of geologic mapping, regardless of the application, e.g., exploration, environmental hazards mapping, or engineering assessment.

To achieve this mapping capability will require the use of spaceborne sensors which, like the Seasat SAR, provide radar sensor data over a relatively wide swath with a relatively small range of depression angles across the swath. In this quantitative effort, it is vitally important to hold the depression angle nearly constant over the region of interest.

Because of the complex nature of radar measurements, it is not enough to look for empirical correlations between radar data and the desired information. There are simply too many variables to attempt to determine the correlation through empirical comparison. Research that resolves the issue will comprise theory, laboratory modeling, and field testing.

Structural Feature Analysis - The capability of radar for imaging subtle structural features--faults, joints, shear zones, and related structures that appear as lineaments in the images--is routinely being exploited in those areas for which radar imagery is available for numerous applications under the general categories of natural resources and hazard assessment.

Radar images have contributed directly to finding ground water in granitic terrains, e.g., in Nigeria, by allowing accurate mapping of intersecting fractures which provide the necessary fracture porosity to serve as reservoirs. Hydrocarbon recovery has been assisted by radar image analyses of structural features which provide an indication of local fracture porosity which correlate with either the migration and loss of hydrocarbons or productive reservoirs. Structural and fracture analyses also reveal the location of subsurface stratigraphic features.

Similarly, geothermal applications generally involve identification of intersecting fractures which provide pathways for hot water and steam. Radar images have been successfully used for this purpose.

In seismically active areas such as California and the Phillipine Islands, radar imagery has been used to assess seismic risk at sites of planned and existing structures, notably dams and nuclear power plants.

Rock Type Discrimination - Through the use of radar imagery, the geologist may identify and map general lithologic categories, e.g., sedimentary, metamorphic, extrusive and intrusive bodies and various alluvial and aeolian deposits. This has been repeatedly demonstrated. However, the identification and classification of specific rock types, for example, sandstone versus shale, from radar imagery is rarely possible without supporting geologic data. This aspect of rock type discrimination from radar imagery needs additional study.

Drainage Pattern Analysis - The pattern produced by stream courses are especially well displayed in radar images. Analysis of drainage patterns is a very good indicator of lithology and subtle surface morphology or structure. Drainage density can be a measure of rock permeability, while pattern indicates surface form and structure.

Surface Roughness - Surface roughness has a marked effect on the radar reflectivity. This effect has been successfully used to discriminate fine and coarse-grained soils, lava flow, evaporites and anomalous lithologies on opposite sides of faults. However, specific identification and classification of material types is rarely possible with the current measurements and interpretation capability.

APPLICATIONS

Geologists study aspects of the earth for a variety of reasons. The exploration geologist is interested in locating previously unknown occurrences of hydrocarbon or mineral commodities which can be extracted economically. A geologist working on a civil works project may want to ascertain that a dam or road being constructed is being built in the best possible location from a safety and stability point of view. An environmental geologist may be interested in determining the earthquake hazard of an urban area or in determining the waste disposal parameters associated with the construction of a nuclear power plant. A ground water geologist may be interested in developing a new water supply for a rapidly growing community. Yet, all these geologists have common data requirements which can be grouped into a few generalized informational needs. This is particularly true when considering these needs in view of which data and information can realistically be obtained by remote sensing techniques.

These application needs include:

1. An ability to define, as accurately and in as much detail as possible, the structural geology (fold, faults, fractures, etc.) of the area being studied.
2. An ability to discriminate and identify lithologic (rock type) variations; and
3. An ability to discriminate and identify specific landforms (because of their significance in structural and lithologic interpretations and because of the specific individual importance).

POTENTIAL

Active microwave sensor data are not expected to be capable of providing all of the information needed in the applications noted. These data will likely always be used in conjunction with other remotely sensed and ancillary data. However, there are unique informational characteristics provided by radar sensor data which should significantly improve the ability to define several critical application parameters. These include:

1. Unique identification of important but obscure structural features.
2. Improved landform identification.
3. Improved rock type discrimination (textural) properties.

The characteristics of radar imagery which provide the unique and complementary characteristics are:

1. All weather capability.
2. All latitude capability.
3. Selectable angle of incidence and look direction.
4. Multifrequency capability.
5. Multiple polarization capability.

Radar imagery provides excellent information related to geologic structure. The potential exists, and has been repeatedly demonstrated, for identification of subtle structural features on radar imagery. In a study in Wyoming,

several short, mapped linear segments were connected based on information obtained from a radar image, even though there was no topographic expression of the fault surface. The texture change across the fault, as mapped from the radar image, displayed the offset. Information obtained in the visible and near-infrared regions can strongly supplement most structural interpretations.

The improved landform identification provided by radar imagery is due to the topographic enhancement arising from the ability to select look direction and angle of incidence. Landforms generally can be identified on radar imagery faster and with greater accuracy than on any other single remote sensing source. However, visible and near-infrared data can provide a large amount of landform related information. In combination, radar imagery and the visible and near-infrared data provide for extremely accurate identification of landforms.

Visible and infrared sensor data provide spectral information that is very useful for discriminating rock types and identifying certain types of hydrothermal alteration, but they provide little information about the physical properties of various rock types or weathering surfaces. Surface roughness is an additional important characteristic which can also be used to discriminate lithologic units. It has been demonstrated in several studies that the information on surface roughness supplied by a radar sensor adds to the discriminability of sedimentary rock units.

RESEARCH NEEDS

Major uncertainties exist concerning the optimization of instrument parameters for spaceborne radar imaging systems. For geologic applications, many of the variable parameters are scene dependent.

Two approaches to the problem should be taken, depending on the parameters to be considered: (1) existing spacecraft and airborne radar systems should be carefully evaluated and more experiments should be planned and flown; and (2) computer simulations using digitally processed images and digital topographic data bases should be used for a variety of terrain types as a cost-effective means of examining many individual variables and for studying the optimum geometry for radar stereo. The computer simulations can provide insight into problems or advantages inherent in the use of radar at orbital altitudes.

Following is a brief summary of some of the parameters that need to be studied.

Look direction - The detectability of structural features depends on their orientation relative to the flight path. Studies performed to date indicate that at least two look directions, preferably orthogonal, are needed for maximum data extraction.

Depression angle - Previous airborne experiences have usually been at low depression angles (10° - 40°). This work provides the basis for enhancing subtle topographic features. High depression angles give reflectivity information that is proving useful in analysis of flat-lying coastal regions. Seasat SAR images are difficult to impossible to interpret in mountainous regions.

Terrain variations in topography and cross section - The inherent variations in the terrain determine the system dynamic range and grey level discrimination requirements. The limits of backscattering variation for natural terrains needs to be understood. This can be simulated for the spaceborne case by applying various backscatter models.

Polarization - The utility of multiple polarization radar images for geology applications needs to be studied further. Differences in the like and cross-polarized images are observed, but systematic analysis of the cause of these variations has not been performed. Techniques might also be developed to separate effects of slope and surface roughness using two different polarizations.

Resolution - It will be necessary to examine the resolution requirements for identification of various geologic targets to provide the rationale for a particular system resolution. Most geologic features are areally extended targets amenable to detection by moderate resolution systems. However, resolution requirements for cartographic purposes need to be defined.

Frequency - More work must be done to determine whether a particular single frequency is best for geologic analysis, and whether a multispectral radar is beneficial in a way analogous to the way in which multispectral imaging in the visible and infrared regions has aided remote sensing studies.

Stereo - Studies must be performed over a variety of targets and a range of incident angles for both same and opposite-side stereo. Most sources report that for conventional stereo viewing, same-side stereo is best in average terrain. This can be studied by aircraft and by computer simulations. Quantitative recovery of topographic data should be studied.

RECOMMENDATIONS

1. An imaging radar system operating at X-band (3 cm wavelength) with a 45° depression angle in a Landsat-type orbit should be flown as soon as possible to acquire data of proven value for mineral and energy exploration.
2. On-going, coordinated research should be conducted by geologists on the following topics:
   a. Surface roughness and reflective properties as guides to composition and distribution of geologic units.
   b. Polarization, frequency, and depression angle dependency of response from geologic indicators.
   c. Stereoscopic radar images as aids to geologic interpretation and measurement of vertical relief.
   d. Radar backscatter from vegetation or indicators useful to geology and engineering applications.
   e. Requirements for seasonal, synoptic coverage from free flying satellites.
   f. Capability of orbital imaging radar sensor data for environmental monitoring, e.g., oil seeps and spills.
3. Research should be conducted by system specialists on the following topics:
   a. Optimization of radar sensors for geologic applications with emphasis on dynamic range, resolution, stereo imaging, wavelengths, polarizations (including cross-polarization), and depression angle.
   b. Applications of automated analysis techniques, including pattern recognition, texture analysis, and shape recognition.
4. Existing radar data should be made available in standardized format to the user community.
5. Current NASA radar systems should be available to users and commercial data acquisition and analysis systems should be utilized as appropriate to support experimentation.
6. Training in radar data analysis and interpretation, together with evaluative and interpretive experiments, should be funded to maximize use of radar data by practicing geologists.
7. The design of future radar systems for geology applications should involve close communication between the user community and the system engineers.

AGRICULTURE

In February, 1978 the Secretary of Agriculture issued a statement entitled "A Joint Program of Research and Development of Uses of Aerospace Technology for Agricultural Programs." This statement, generally referred to as the Secretary's Initiative, identified several important USDA information requirements that aerospace remote sensing data would fulfill to some degree.

In response to these stated requirements, a six-year program of research, development, evaluation and application of aerospace remote sensing began in October, 1979. This joint effort of USDA, NASA, USDC, USDI, and AID is entitled Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing and is known by the acronym AgRISTARS.

There is a high degree of interrelationship between the applications identified in this section and the focus of the AgRISTARS effort. The candidate applications of SAR technology presented here have been grouped into three broad categories which include mapping and monitoring of:

1. Crop Lands
2. Forest Lands
3. Rangelands

Each of these categories and their attendant applications can be correlated to specific elements in the AgRISTARS program.

STATE OF KNOWLEDGE

Crop Lands

Knowledge of the spatial and temporal distribution of soil water is of economic and scientific significance to several agricultural, hydrological and meteorological applications. The combination of radar's weather-independence and high resolution capability, together with the strong dependence of the microwave dielectric constant of soil on its water content, makes the radar sensor a prime candidate for mapping soil moisture from aircraft and satellite platforms.

Present evidence shows conclusively that radar data are responsive to soil moisture variations. The bulk of the evidence has been accumulated in the last five years from calibrated truck-mounted radar sensors. These were used to measure the dependence of the scattering coefficient on soil moisture content and on surface roughness and vegetation cover so that the latter dependence can be minimized by properly choosing the sensor parameters (microwave frequency, angle of incidence, and polarization configuration). The results indicate that by operating at a frequency in the 4 - 5 GHz region over an angular range between 7° and 17° from nadir, the radar scattering coefficient is strongly correlated with soil moisture content, and almost independent of surface roughness and vegetation cover of agricultural crops. Because of the dependence of the dielectric constant of soil on soil texture (type), it was found necessary to express moisture content in terms of a texture-independent parameter. The parameter currently used is percent of field capacity, where field capacity is defined as the moisture at 1/3 bar tension.

A brief summary of the capability of radar as a soil moisture sensor is presented in Figures 2-4. Figure 2 shows the relative independence of the radar backscattering coefficient of surface roughness of bare soil. Figure 3 shows the response to soil moisture of vegetation-covered soil. Figure 4 shows the variation for both bare and vegetated fields. Results obtained to date indicate that the effective depth influencing the radar backscatter varies between the top 5 and 15 cm of the soil.

Radar backscatter measurements of crops by University of Kansas investigators have shown that:

1. Multi-temporal observations of corn, wheat, milo, and soybeans at 10-day intervals, in the 40°-60° angle of incidence range, at frequencies above 8 GHz, can provide classification accuracies higher than 90% after 3 or 4 passes. This performance is repeatable from one year to the next (Figure 5).

2. Using a minimum combined configuration of two Landsat MSS bands (5 and 7) and one radar frequency (two polarizations), crop classifications exceeding 95% accuracy were attainable for data obtained at two dates in time segment I (prior to wheat harvest) as shown in Table 2. The same sensor combination produced classifications close to 90% accuracy for the second time segment (after wheat

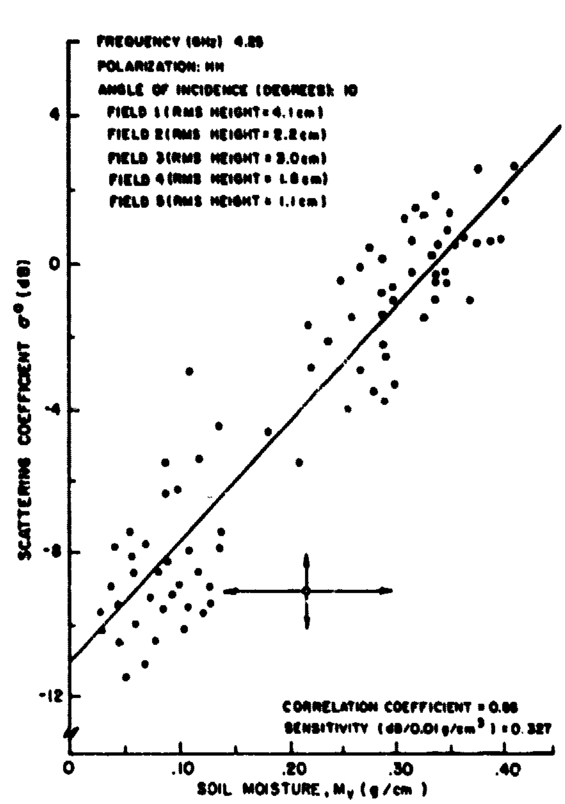

Figure 2. Relative Independence of the Radar Backscattering Coefficient of Surface Roughness of Bare Soil

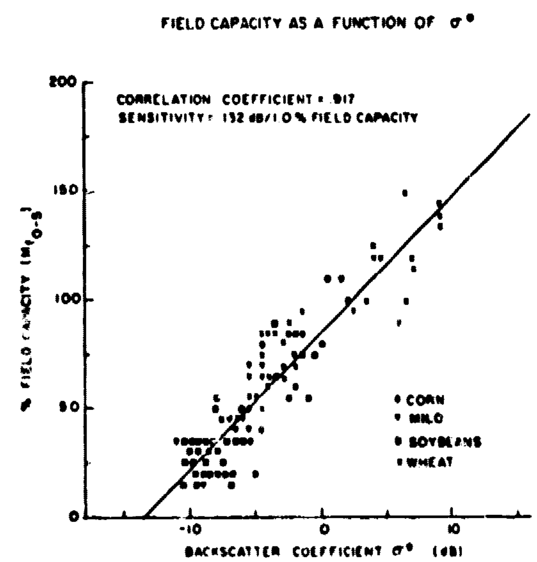

Figure 3. Response to Soil Moisture of Vegetation-covered Soil

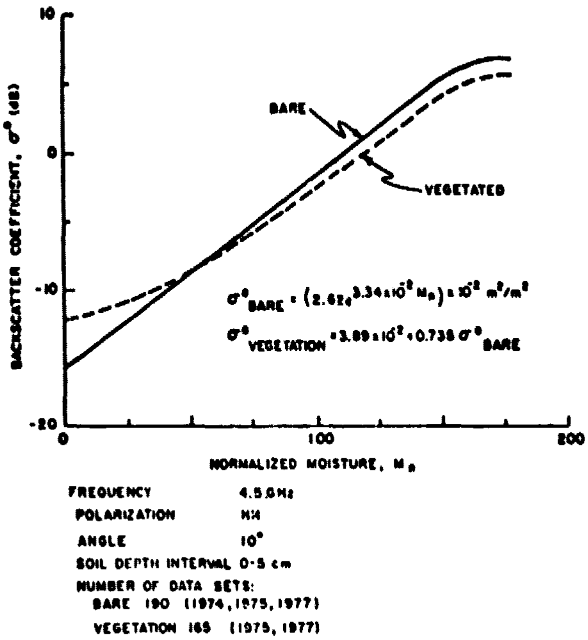

Figure 4. Variation for Both Bare and Vegetated Fields

harvest), as shown in Table 3. The classification statistics clearly showed that the data from each sensing system were complementary, which resulted in mutual reinforcement and an increase in discriminating accuracy between crops.

3. The effects of cloud cover were evaluated by comparing crop classification accuracy obtained with Bands 5 and 7 of Landsat with one date missing due to cloud cover, with the accuracy obtained using radar data to replace the missing Landsat coverage. The availability of radar to replace missing Landsat data results in substantial improvement in classification accuracy.

4. Observations of the temporal variation of the radar backscattering coefficient of agricultural crops over their growing cycles indicate a potential for estimating yield related parameters such as leaf area index and canopy water content.

At the present time, there are no ongoing or planned research programs to continue the work conducted on combined Landsat-radar crop classification. Previous work was conducted using radar data acquired from a truck platform.

Forest Lands

Existing evidence from ground based field experiments and interpretation of aircraft SAR data indicates the following capabilities of single frequency SAR data for forest resources assessment:

1. The areal extent of forested lands can be defined.
2. Clear cutting areas are obvious on SAR data and undoubtedly can be defined within known forested areas.
3. Differences in heights (due either to growth stages or to tree type) can be qualitatively indicated in low density stands or along stand boundaries.
4. Canopy density can be indicated qualitatively.

Multifrequency SAR data appear to be capable of the following:

1. Deciduous trees can be discriminated from conifers in both winter and summer.
2. Long needle conifer species can be discriminated from some short needle species.

APPLICATIONS

The key applications within the general discipline of agriculture to which aerospace remote sensing technology can be applied are shown in Table 4. The importance of each and the rationale for their selection are described in this section.

Crop Lands Information Needs

Accurate and timely commodity production information is essential to the development and maintenance of an adequate world food supply and to help ensure that the U.S. producer receives a fair market price and that the U.S. benefits from a more favorable balance of trade resulting from agricultural exports.

In the past two decades, a variety of remote sensing experiments have demonstrated that visible and infrared data and associated data analyses techniques are capable of providing significantly improved commodity production information. Without remote sensing techniques, conventional survey approaches have not been able, in foreign countries,

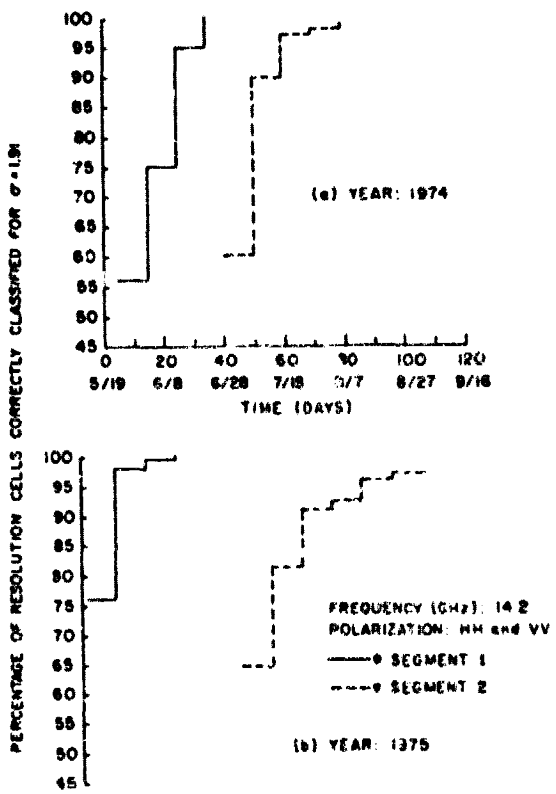

Figure 5. Percentage of cells correctly classified plotted as a function of time with a revisit interval of 10 days. The drop between segment 1 and segment 2 is due to wheat harvest and replanting with new crops. a) Based on 1974 data and b) based on 1975 data.

Table 2. OVERALL PERCENT CORRECT CLASSIFICATION FOR VARIOUS SENSOR COMBINATIONS (FIRST SEGMENT)

	ALL CLASSES[1]			CROPS[2]		
	5/20	6/16	6/28	5/20	6/16	6/28
LANDSAT						
BANDS 5 AND 7	65.6	82.4	88.1	88.4	80.4	83.4
BANDS 4,5,6 AND 7	71.8	85.7	87.5	84.0	84.4	86.4
RADAR						
10.6 GHz (HV,VV)	87.4	93.3	95.2	80.2	92.8	92.4
14.2 GHz (HV,VV)	86.9	96.1	97.3	79.1	93.8	95.6
10.6, 14.2 GHz (HV,VV)	94.0	99.6	99.6	90.5	99.5	99.9
COMBINED						
RADAR 10.6 GHz (HV,VV) LANDSAT BANDS 5 AND 7	92.3	96.9	97.1	88.1	96.1	96.4
RADAR 14.2 GHz (HV,VV) LANDSAT BANDS 5 AND 7	89.5	97.6	98.7	83.6	96.7	98.0
RADAR 10.6, 14.2 GHz (HH,HV,VV) LANDSAT BANDS 4,5,6 AND 7	94.6	99.7	99.7	91.4	99.5	99.9

[1] TREES, WATER, HIGHWAY, CORN, WHEAT, MILO

[2] CORN, WHEAT, MILO

Table 3. OVERALL PERCENT CORRECT CLASSIFICATION FOR VARIOUS SENSOR COMBINATIONS (SECOND SEGMENT)

	ALL CLASSES[1]			CROPS[2]		
	8/09	8/19	8/27	8/09	8/19	8/27
LANDSAT						
BANDS 5 AND 7	78.9	87.9	87.9	69.3	84.2	94.0
BANDS 4,5,6 AND 7	80.0	86.7	88.1	72.7	82.9	94.4
RADAR						
10.6 GHz (HV,VV)	68.7	76.6	82.9	46.5	62.6	72.2
14.2 GHz (HV,VV)	68.0	72.2	73.6	40.1	55.8	58.0
10.6, 14.2 GHz (HV,VV)	74.9	81.6	88.4	59.6	70.7	81.6
COMBINED						
RADAR 10.6 GHz (HV,VV) LANDSAT BANDS 5 AND 7	86.4	92.6	94.7	78.4	88.6	91.6
RADAR 14.2 GHz (HV,VV) LANDSAT BANDS 5 AND 7	84.8	93.1	93.3	75.8	89.3	89.3
RADAR 10.6, 14.2 GHz (HH,HV,VV) LANDSAT BANDS 4,5,6 AND 7	87.5	96.1	96.3	80.2	92.2	94.2

[1] TREES, WATER, HIGHWAY, CORN, SOYBEANS, MILO

[2] CORN, SOYBEANS, MILO

Table 4. KEY APPLICATIONS IN AGRICULTURE TO WHICH REMOTELY SENSED DATA CAN BE APPLIED

CROPLANDS

1. Improved commodity production information
   a. Acreage information of selected crops
   b. Yield information
   c. Crop state information
2. Information related to the soil resource
   a. Increased timeliness in the preparation of soil maps
   b. Determination of crop growth potential
      (1) salinity detection and mapping
      (2) soil erosion monitoring
      (3) soil moisture assessment
   c. Assessment of soil and conservation practices

FOREST LANDS

1. Forest resource assessment in the U.S.
   a. Determine extent and condition of forest resources
   b. Map forest resources by cover type and density and size classes
   c. Monitor changes in the forest resource base
   d. Monitor location and extent of forest stress conditions due to insects and disease
   e. Monitor forest fuel condition
   f. Wetlands and wildlife habitat assessment
2. Forest resource assessment in other temperate regions of the world
   a. Determine extent and condition of forest resources
   b. Monitor changes in the forest resource base
3. Tropical forest assessment
   a. Map areal extent and major categories of tropical forests on a global basis
   b. Determine extent and rate of infestation of topical forest lands by country

RANGELANDS

1. Vegetation mapping
2. Productivity assessment
3. Range condition and trend assessment
4. Monitoring of intensive grazing management systems
5. Monitoring of changes in wildlife habitats

to provide timely and accurate crop information. In many of these regions, foreign governments either do not collect or release objective crop data. Among the information needed for timely and accurate commodity production forecasts are the following.

Acreage - The planting and harvesting of major crops occurs throughout the world on nearly a continual basis. Thus, crop monitoring calls for a nearly continuous activity. Early in the crop season for a region, the most important information to be obtained is the acreage planted for all crops. Next, timely estimates of the emerged and standing acreage are crucial to assessing production potential. As the season progresses, monitoring of acreage losses or abandoned acreage to weather events such as freeze damage or drought, or to agricultural practices such as grazing by cattle, is important. At season's end, the estimate of harvested acres provides the base by which to estimate total production, given estimates of the yield for harvested acres.

While visible and infrared data from aircraft and space scanners provide such information with reasonable accuracies, these data can be acquired only in daytime and under a limited range of atmospheric conditions. With microwave sensors, the capability to extend these observations to hazy and cloudy atmospheric conditions and to acquire data at night can provide more timely information at critical times in the season. In addition, the longer wavelength microwave radiation responds to the electrical volumetric and geometric properties of crops in a different way than visible and infrared frequencies. This new information may improve the accuracy of crop type discrimination and, thus, improve the clear weather crop identification capability of visible/infrared data.

Yield, Condition, and Crop Development Stage - The ability to assess the effect of past and current conditions on crop yield and to rapidly reassess changes in the crop status is an important capability which can be provided by remote sensing. In early season, available soil moisture and wintering conditions such as snow depth and frozen soil are important factors in determining future crop yield. As the crop progresses, soil moisture as well as canopy biomass, canopy water content, and canopy condition are important factors in final yield. Finally, as the crop nears harvest, knowledge of the precise dates for key crop development stages such as heading or grain filling, are extremely important in assessing weather effects, such as high temperatures, on crop yield.

Some of these key yield related parameters may be uniquely provided by use of microwave sensors, particularly soil moisture. In most cases, use of microwave frequencies in combination with visible/infrared data has potential for the assessment of crop condition and crop development stage; both vital inputs to yield prediction and crop identification.

In summary, the critical commodity production information components amenable to monitoring by microwave sensors are crop extent and distribution, crop canopy density, biomass and canopy micro-environment, e.g., snow depth, soil temperature, soil moisture, the condition of the crop, crop development stage, and phenology information.

While conventional and remote sensing systems exist that can collect such information, significant improvements are required in both the accuracy of the information and the timeliness with which it is obtained. Active microwave sensors have the potential of improving this information. The major attributes of active microwave image data for these purposes are cloud penetration and night capability, response to unique electrical and geometric canopy properties, and volumetric penetration capabilities.

Soils Information Needs

Crop production potential depends upon meteorological and soil conditions. Since man has some control over soil conditions, it is important that the soil resource be managed to provide favorable conditions for optimal crop production. Within the framework of a soil management scheme, it is necessary to know the static and the dynamic characteristics of the soil.

The static characteristics are the texture of the horizons of the soil profile. The dynamic characteristics are the saline status, erosion status, and the soil moisture status of the soil. Remote sensing techniques have the potential for assessing the static characteristics of soils, and monitoring the dynamic characteristics of soils.

The Soil Conservation Service is responsible for classifying soils of the United States. The present classification procedure requires a large commitment in both time and manpower. Due to limited manpower resource, there is a significant delay in the production of useful soils information for many regions of the United States. The development of a more rapid soil survey procedure is desirable. The use of remote sensing techniques could speed the present procedures.

The reclamation of saline/sodic soils requires that the magnitude and extent of the saline/sodic condition first be determined. Individual landowners can perform this determination on their own. However, national policy assessment of the problem requires regional monitoring and mapping. Remote sensing techniques are the most suitable for performing this task.

Soil erosion has an impact on present water conservation and upon future soil productivity potential. The Soil Conservation Service is responsible for overseeing the maintenance/improvement of the soil productivity in the United States. This federal agency is therefore interested in estimating soil losses from crop land. A monitoring program would be useful in this area to assist in formulating these estimates, and in locating those areas where land management has to be improved to reduce soil erosion potential. Remote sensing techniques are a required tool to provide this type of information.

The whole problem with soil moisture monitoring deals with attempting to determine soil moisture levels over a large area when generally there are only point measurements available. The monitoring of soil moisture variations in both space and time would be of value to the assessment of crop yield, as well as to the assessment of several hydrologic processes. Remote sensing techniques may be a valuable tool to extrapolate point measurements to areal variations.

The soil and water conservation practices implemented under the direction of the Soil Conservation Service are important with regard to maintaining crop production potential. Some of these practices are contour terracing, land leveling, land shaping, wind rowing, strip-cropping, and stream stabilization. It is difficult to assess the effectiveness of these improved practices from the ground, even on a case-by-case basis. Remote sensing techniques should be helpful in assessing the effectiveness of these practices when the techniques are used to monitor temporal changes.

Forest Lands Information Needs

Determine extent and condition of forest resources - The Resources Planning Act (RPA) of 1974 mandates the U.S. Forest Service to determine the extent and condition of the forest and rangeland resources of the U.S. every ten years. The Forest Service is currently developing techniques to meet this requirement using satellite (Landsat), aircraft, and ground-based data. The approach will involve multi-stage sampling to provide tabular information on a county-by-county basis, but will not require complete map information.

Map forest resources by cover type, and density and size class - Different users have different information requirements. Private industry, state Departments of Natural Resources, and National Forest Service personnel, for example, require maps showing the physical location and

volume of the forest resource. This type of information is usually obtained at present on a periodic basis with aerial photography.

Monitor changes in the forest resource base - Urban expansion and changes in the demand for agriculture land cause continuous change in the areal extent of the forest resource base. Both local and national predictions of timber productivity require effective monitoring of changes in the resource base on a cycle that is more frequent than the 10-18 year cycle currently achieved by the U.S. Forest Service. Private industry would like to be able to monitor changes on an annual basis and within a defined annual planning cycle. In some states, clear-cutting of forest areas must be monitored in a timely manner (perhaps monthly), for tax assessment purposes.

Monitor location and extent of forest stress conditions due to insects and diseases - The U.S. Forest Service and others need to determine the location and extent of dying and dead timber in order to salvage this otherwise wasted timber, and also to remove a source of potential insect population growth. It has been stated that this information need "is currently the single most important data requirement for which data collection and sampling methods are lacking." ("Applications Review for a Space Program Imaging Radar," Geography Remote Sensing Unit Technical Report I, University of California, Santa Barbara.)

Monitor forest fuel condition - Forest fires destroy millions of dollars worth of resources every year. To aid in forest fire prevention efforts, the U.S. Forest Service maintains a fire danger rating system. The forest fuel condition, involving such parameters as the fuel amount and moisture condition, is a key element in providing data input to the fire danger rating system.

Wetlands and wildlife habitat assessment - Wetlands mapping of both coastal and interior wetland areas is of critical importance in many aspects of land use planning and wildlife management. USGS is currently heavily involved in a major wetlands mapping program.

Determine extent and condition of foreign forest resources - F.A.O. and other agencies involved with evaluating and monitoring natural resources on a worldwide basis need more reliable information of the forest resources.

Monitor changes in foreign resource bases - Due to the long term growing cycle of the forest resource, the capability to monitor changes is important to the country involved, planning groups in the U.S., as well as international agencies.

Map areal extent and major categories of tropical forests on a global basis- Many of the developing countries of the world have relatively poor information concerning the nature and extent of their forest resource base. Because of the remoteness and size of the areas involved, it is difficult to obtain accurate, reliable information on these areas. The persistent cloud cover over many of these areas compounds the problem. The unique capabilities of radar indicate the potential of using this data source as a means of obtaining the needed information.

Determine extent and rate of deforestation of tropical forest lands - In a number of tropical countries, deforestation is occurring at an increasingly rapid rate. Brazil, the Phillipines, Thailand, among others, have experienced severe decreases in the areal extent of forest within the past 10-15 years. This problem is of major concern to the F.A.O. and many other agencies from three aspects: (a) decreasing wood supplies; (b) possible correlation between the decreases in tropical forest lands and the well-documented increasing levels of CO_2 in the atmosphere on a worldwide basis; (c) increasing desertification in some regions that is associated with the denudation of the forest resource for fire wood.

Rangelands Information Needs

Rangelands consist of those terrestrial habitats that are not intensively cropped and that provide forage for domestic livestock and wildlife. This includes some 40% of the land mass on a worldwide basis. It consists of grasslands, shrublands, savannahs, desert scrub, tundra, some grazed wetlands and grazed forest areas. This diverse vegetation resource requires continued monitoring and management in order to maintain and enhance productivity.

Rangelands in the United States are managed by various entities, including the Bureau of Land Management (USDI), U.S. Forest Service (USDA), U.S. Fish and Wildlife Service (USDI), State Rangeland Agencies, private ranches, and corporate ranches and landholders.

The federal rangelands, particularly those managed by the Bureau of Land Management, are under a mandate to complete over the next 12 or 13 years, a series of site specific environmental impact reports. The data base upon which these environmental impact reports must rely are presently inadequate. Rapid, low cost procedures are required because of the large low-productive areas that are involved. Following acceptance of these environmental reports, there will follow a period of intensive management based on allotment management plans. It is important that these management programs be carefully monitored in order to evaluate their effectiveness.

In addition, the recent Rangeland Improvement Act will soon provide money for considerable range improvement work on U.S. rangelands. These improvements must also be monitored and evaluated.

Over much of the United States and most of the rangelands of the rest of the world, there is a limited amount of area-extensive data on range productivity and trend. The ground methods are too costly to be used except for specific cases. Therefore, remote sensing may offer the only feasible means of gathering such data over these rangelands.

The information desired from remotely sensed data includes:

Vegetation mapping - Identify and measure the distribution of the various rangeland plant communities. This should be approached from a synecological viewpoint (community ecology) based on correlations with landform and soil classification units. Species identification is required.

Productivity - Initially assess range vegetation productivity of the various range plant communities. This is related to livestock productivity. A knowledge of forage productivity is required to set carrying capacity. Some of the vegetation and site parameters that must be included are vegetation cover (foliar projection onto the ground), vegetation density (individuals/unit area), biomass (weight and/or volume/unit area), and bare ground and litter (important in shrub-dominated rangelands). These factors are all related to range condition and trend. All of the productivity parameters must be determined by species or by group of species with similar characteristics.

Monitor range condition and range trend - The assessment of range trend is related to phenology which is regulated by soil moisture content, soil air temperature. and day length. Phenology is closely related to range readiness on seasonal ranges. Range trend monitoring relates to perturbations on rangelands, e.g., vegetation changes induced by fire, insect or pathogen damage; accelerated erosion; and heavy overgrazing.

Monitoring of intensive grazing management systems - This involves a monitoring of productivity, range condition, and range trend. Trend assessment is difficult to do with most remote sensing techniques because of the requirement for species identification. There is need to evaluate the success

or failure of range improvement practices.

Monitoring of changes in wildlife habitat on rangelands -This is related to fluctuation in wildlife populations or the occurrence of perturbations that might destroy or reduce the value of these habitats.

The above items are not presently satisfied with existing data sources. Ground techniques have proven too costly over the extensive, relatively low value rangelands in the United States and abroad.

POTENTIAL

The major attributes of active microwave image data of particular value to agricultural applications are:

1. Timeliness (weather independent system).
2. Penetration capabilities.
3. Response to electrical and geometric properties of the target.
4. High resolution from space.
5. Potential for higher data sampling frequency.

Two fundamental attributes of radar provide advantages in sensing all renewable resource applications: (1) radar penetrates clouds, and (2) radar (SAR) resolution is essentially independent of distance to the scene.

The penetration of most cloud cover enables imaging at most times, in contrast to the cloud-restricted imaging of Landsat. In monitoring of growing vegetation, several temporal and spatial limitations are imposed by Landsat imagery. Clouds can often prevent sequential imaging of a specific area, and can also restrict the spatial extent displayed in Landsat imaging. These restrictions are mostly eliminated with imaging radar. The continually changing conditions of all vegetation require timely observation in order to properly plan at both national and local levels. Severe economic consequences can occur because of improper planning based on incomplete data.

In addition to achieving timeliness of data gathering in moderately cloud-covered regions, the cloud-penetrating radar can be used to obtain images of regions which are perpetually cloud-covered, such as the Amazon basin.

Because the resolution of synthetic aperture radar is essentially independent of distance to the scene, spatial precision can be achieved with satellite radar comparable with that of any future sensors of visible and near-infrared wavelengths. With fine resolution, small areas can be monitored and the accuracy of boundaries and integrated areas can be improved. The evaluation of the distribution of vegetation types would be made more accurately. Examples are the improved evaluation of the total area of a crop, e.g., wheat over a region and, in forestry, an accurate compilation of clear cut areas.

The sensitivity of microwave energy to roughness and geometrical shape enables radar to sense structure. As the structure (including surface roughness) often identifies the material or vegetation, radar sensing can be used in a much different domain than that of Landsat.

An example of sensing of structures is that of long and short needle conifers. Long needles produce a higher return on L-band than short needles, so the difference between X and L-band reflections indicates the type of conifer. Deciduous trees produce an extremely high return on L-band as compared to X-band.

Another effect which is pronounced in radar images is the difference in height of trees and shrubs. The imaging geometry of side-looking radar, coupled with the roughness sensitivity, enhances the measurement of changes in the height of vegetation canopies. Such height discrimination is seldom seen in Landsat data.

The potential of active microwave image data for forest resource assessment is significant. SAR sensors have certain capabilities that offer unique advantages for forestry applications as compared to other data collection systems. These include:

1. The ability of SAR data to provide differences in return that are related to stand density and structure offers the potential to more effectively differentiate among various species and forest cover types than may be possible with MSS data, even from the Thematic Mapper (TM). The combination of SAR and TM data would appear to offer the greatest promise for mapping forest cover types and defining density and size classes.
2. The potential of SAR data to map and monitor deforestation of tropical forest lands is of particular importance from two standpoints: (a) SAR can obtain data in areas of persistent cloud cover, and (b) differences in stand structure such as a fairly recent clear-cut overgrown with brush and a full size jungle forest canopy, should be apparent of SAR, whereas such differences may not be particularly evident in the optical portion of the spectrum. Monitoring the extent and rate of deforestation of tropical forests should be given high priority because of these unique capabilities of SAR sensors and the importance and concern for this application.

The rangeland parameters that should be investigated relative to their assessment by SAR sensors are:

1. Total canopy cover.
2. Bare ground and soil moisture content.
3. Moisture content of vegetation.
4. Some phenological expressions as they relate to either plant moisture content or radar texture based on subtle changes in species or vegetation surface geometry.
5. Vegetation structure or geometry, including height, to determine the potential of SAR to use changes in vegetation structure and height within the stand to infer species composition, or at least the presence or absence of certain important species within the stand. In this way, it might be possible to obtain some information relative to species composition changes.
6. Detailed landform depiction may lead to better evaluation of landform-soil-vegetation correlations.

Vegetation geometry and height are factors not easily inferred from Landsat MSS data. Stereo photography at relatively large scales (1:2,000 or better) is about the only means of evaluating species or stand geometry and relating the information to rangeland attributes, such as leaf area index, productivity and carrying capacity, species density, and species composition.

Table 5 provides a generalized indication of the relative importance of optical and microwave sensor data; the approximate frequency of data collection needed in various application areas; the estimated level of research effort required to meet the various objectives; an evaluation of the probability of achieving a relatively high degree of success; and the priority that should be assigned to the particular application.

RESEARCH NEEDS

Radar backscatter is a function of geometrical and electrical properties of vegetation and the underlying soil. These interactions are not well understood on a theoretical or empirical basis. They involve volumetric scattering properties of the targets which are functions of frequency, incident angles, and polarization of the radar signal. These relationships must be understood in order to extend test site data to broader regions.

It is also essential to relate parameters measurable with radar to physiological parameters that are of interest to the user. For example, if radar backscatter information can be related to physiological parameters such as leaf area, density, vigor, height, water content, etc., models relating these parameters to yield must also be developed for crop prediction.

Future research needed in the crop lands application area fall into two categories:

1. Determination of radar response from complex vegetation systems in terms of the target geometry and electrical parameters. Develop models to predict a series of ground-based, controlled experimental measurements.
2. Define the experiments required to relate physiolog-

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TABLE 5. ACTIVE MICROWAVE SENSOR POTENTIAL AND GENERAL STATUS FOR AGRICULTURAL APPLICATIONS

APPLICATION TASK	ROLE MSS	ROLE SAR	FREQUENCY OF SAMPLE	RESEARCH EFFORT REQUIRED	SUCCESS POTENTIAL	PRIORITY
IMPROVED CROP PRODUCTION PREDICTION						
A. ACREAGE	P	C	MONTHLY	H	H	1
B. YIELD INFORMATION	P/C	P/C	BI-MONTHLY	VH	M	1
C. CROP STORAGE	P/C	P/C	BI-MONTHLY	H	M/H	1
SOIL RESOURCE						
A. SOIL MAPS	P	C	10 YEARS	H	H	1
B. CROP GROWTH POTENTIAL						
1. SALINITY	C	P	ANNUAL	H	L/M	3
2. SOIL EROSION	C	P	ANNUAL	H	L/M	3
3. SOIL MOISTURE	C	P	3 DAYS	H	M	1
C. SOIL AND WATER CONSERVATION PRACTICES	P/C	P/C	ANNUAL	M	H	3
FOREST RESOURCE ASSESSMENT IN U.S.						
A. EXTENT AND CONDITION	P/C	P/C	5 YEARS	M	H	1
B. FOREST RESOURCE MAP	P/C	P/C	5 YEARS	M	H	2
C. CHANGES IN FOREST RESOURCE BASE	P/C	P/C	ANNUAL	M/H	H	1
D. INSECTS AND DISEASE	C	P	BI-WEEKLY	H	M	1
E. FUEL CONDITION	C	P	3 DAYS	H	M	2
F. WETLANDS AND WILDLIFE	C	P	BI-ANNUAL	L	H	1
FOREST RESOURCE ASSESSMENT IN OTHER TEMPERATURE REGIONS OF WORLD						
A. EXTENT AND CONDITION	P/C	P/C	5 YEARS	M	H	2
B. CHANGES IN FOREST BASE	P/C	P/C	5 YEARS	M	H	2

NOTE: H = HIGH
M = MEDIUM
L = LOW

P = PRIMARY
C = COMPLEMENTARY
1 = HIGHEST PRIORITY

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TABLE 5. CONTINUED

APPLICATION TASK	ROLE MSS	ROLE SAR	FREQUENCY OF SAMPLE	RESEARCH EFFORT REQUIRED	SUCCESS POTENTIAL	PRIORITY
TROPICAL FOREST ASSESSMENT						
A. MAPPING OF AREAL EXTENT & MAJOR TYPE	C	P	5 YEARS	M	H	1
B. DEFORESTATION RATES	C	P	2 YEARS	H	H	1
RANGELANDS						
A. VEGETATION MAPPING	P/C	P/C	10 YEARS	H	H	1
B. PRODUCTIVITY ASSESSMENT	P/C	P/C	BI-MONTHLY	H	M	1
C. CONDITION & TRENDS	P/C	P/C	ANNUALLY	H	M/H	1
D. MONITORING INTENSIVE GRAZING SYSTEMS	P	C	BI-MONTHLY	H	H	2
E. MONITORING CHANGES IN WILDLIFE HABITAT	P	C	MONTHLY	H	H	2

NOTE: H = HIGH; M = MEDIUM; L = LOW; P = PRIMARY; C = COMPLEMENTARY; 1 = HIGHEST PRIORITY

ical parameters of vegetation to radar response parameters. These experiments should be coordinated with sensor measurements and model studies for other wavelengths.

In general, the translation of ground-truth measurement techniques into the design of an operational system requires the incorporation of parameters which are not considered in point measurements. One parameter which introduces a variation is topographic variation across the scene under consideration. Since the ability to appropriately detect a phenomenon may hinge on the use of a specified incident angle or range of angles, strong topographic changes may degrade system sensitivity to the application parameter of interest.

Further research needs include:

1. Sensitivity analyses of incident angle variation on the detection accuracy of the desired parameter of interest.

2. Identify possible techniques to strip SAR data of its topographic information and influence.

Experiments at the University of Kansas using truck-mounted sensors suggest: (1) an improvement of crop discrimination when simulated radar imagery and Landsat data are merged, and (2) a strong correlation between radar backscatter and soil moisture. It is necessary to evaluate these measurements with imaging sensors flown at aircraft altitudes. It is important to determine whether the correlations can be observed under a diversity of natural variations (soil types, surface roughness, variability of planting dates, etc.) over broader areas.

Techniques of merging radar and Landsat imagery that utilize the dynamic range and precision of the r… ır imagery, must be evaluated and optimized. This includes such problems as registration of radar, MSS and other data sets (e.g., topography), and removing effects of radar speckle to allow use of image classification algorithms.

The future research needed to establish the role of active microwave sensor data for applications involving forest lands includes:

1. Use of SAR for tree species identification. Determine the species that can be discriminated and the level of accuracy and reliability.

2. Determine capability to ascertain timber volume (as related to stand density and tree height) using SAR data.

3. Develop capability to automatically define the location and the extent of change in forest cover.

4. Determine capability to assess the condition of tree vigor, particularly in relation to diseases and insect infestations.

Essentially, there has been no useful research conducted on the problems of obtaining rangeland management information with SAR. Therefore, an experiment or series of experiments should be conducted that would provide for an evaluation of SAR as a means of evaluating range productivity and trend. Such an experiment should involve an indirect approach using scene roughness, tone, vegetation, height, soil and/or vegetation moisture content, amount of bare ground and other factors possibly measurable by SAR, to model or infer the productivity of the site or changes in productivity. Such an experiment should be conducted at a location where there is considerable ground data and where complementary Landsat MSS and aerial photographic information can be made available.

ECOMMENDATIONS

1. Vigorously pursue the definition and development of a research program involving ground-based and aircraft systems (both microwave and optical) to address the research needs defined in this report.

2. Define a set of prime test sites involving crop, forest, and rangeland areas on which combined SAR/MSS research would be conducted.

3. Pursue definition of satellite SAR program to meet the information requirements in agriculture--many of which can only be met with SAR data. Many of these information needs are vital to effective management of crop, soil, forest, and rangeland resources, both within the U.S. and on a world-wide basis.

4. Develop data processing techniques to effectively utilize SAR data and to combine SAR and MSS data.

5. Pursue ongoing technology transfer effort within the scientific community to develop a better understanding of capabilities and limitations.

LAND COVER

There are three primary application areas in which data needs are not currently being met by available sensors, and where significant benefits potentially could result from application of active microwave remote sensing. These are:

1. Comprehensive mapping of current land use. Active microwave remote sensing potentially could be used to improve the accuracy of land use/land cover classification, both in terms of category identification and boundary delineation.

2. Provision of land use/land cover data for land use and natural resources planning and management. There are specific needs for improvement of inventory and monitoring techniques.

3. Disaster monitoring. Development of a capability for early change detection and damage assessment related to floods, fire, wind, earthquakes, landslides, and volcanic eruptions is needed.

STATE OF KNOWLEDGE

Current understanding, with respect to land resource applications of active microwave imagers, is documented in previous workshop symposium reports. They suggest a considerable amount of uncertainty as to the type and accuracy of information that can reliably be extracted from active microwave remote sensing. For example, the National Research Council Committee on Remote Sensing Programs for Earth Resources Surveys ("Microwave Remote Sensing from Space for Earth Resource Surveys," 1977) concluded that the experimental data base was too limited to judge the potential usefulness of active microwave sensors for vegetation classification and for land use. The Committee generally concluded that it was not clear that radar imagery would provide a significant addition to existing information sources. Nevertheless, the panel believes that there are potential applications of active microwave sensor data in a number of important areas identified in this report, and that these applications are sufficiently promising to merit further investigation.

The Seasat SAR sensor has already been found to hold promise. For example, preliminary findings indicate that Seasat SAR data may be able to separate forested wetland from dryland forests. The tree canopies would appear very similar in Landsat images taken during the in-leaf period.

The NASA "Shuttle Active Microwave Facility Review" of 1978 concludes that: "Active microwave measurements of the reflectance characteristics of vegetation canopies have shown these data to be sensitive to crop type, stage of crop growth, and plant moisture. Experiments conducted over the last decade to determine the data needs in the renewable resources area which can best be satisfied with active microwave sensor measurements have shown that the optimum radar wavelength, polarization, and illumination angle vary significantly with the application. For example, vegetation measurements are facilitated by short wavelengths and large incident angles, whereas soil moisture measurements generally require long wavelengths and small incident angles."

Other reports indicate that:

1. Improved land cover classification due to the use of Seasat SAR data as an additional spectral band has been demonstrated.

2. Category boundary delineation, particularly land/water boundaries, may be significantly increased in accuracy by the use of Seasat SAR data.

3. Urban category and boundary delineation appears promising by the use of active microwave data.

APPLICATIONS

The panel feels there are three important applications areas which should be investigated:

1. Comprehensive mapping of current land use/land cover patterns;

2. Surveys of specific land use/land cover types for natural resources planning and management; and,

3. Disaster monitoring.

In each of these areas, to a greater or lesser extent, significant current information needs are not adequately being addressed by current sensor systems. While there is reason to hope the future higher spatial, spectral, and temporal resolution satellite sensor systems operating in the visible and infrared portions of the electromagnetic spectrum will help satisfy these needs, it is evident that information gaps will still exist.

The user community for information on land use/land cover is very broad. It includes: (1) planners at the Federal, State, and regional levels, as well as in the private sectors; (2) resource managers; (3) researchers in the academic world and government; and (4) a variety of business people and educators. There is an international demand, as well as a domestic one. The need for training programs is a natural follow-up to information dissemination. The demand is a growing one.

Improved comprehensive land cover mapping information is required to increase the usefulness of resource maps utilizing the U.S. Geological Survey mapping scheme developed in USGS Professional Paper 964. More complete Level II category classification is needed for users at the Federal, state and local levels.

Timely coverage is required that would allow the development of regional data bases where the imagery is collected over large geographic areas within a narrow time window.

A surface texture component obtainable with active microwave sensors, when added to the conventional multispectral thematic classification schemes, would provide two important characteristics: (1) category boundary delineation where the field and roadway boundaries that enclose each land cover category are sharply delineated; and (2) improved category classification due to the unique texture component in active microwave sensor data that is added to the visible sensor data. The surface texture component is particularly suited to assisting in the identification and boundary delineation of cultural patterns on the landscape. As the patterns produced by human activity differ from those occurring naturally (i.e., more straight lines with angular surfaces of more uniform dimensions), active microwave sensor data appear to offer the potential for assisting in the accurate, timely delineation of urban areas.

Current land cover information is required for the 300 major metropolitan areas throughout the United States. Large area coverage over multiple swath-widths is required within a three-month period to support a number of state and federal data base programs. Cloud- free coverage is a major element in the uniform collection of the resource information over large areas and it therefore would be aided by a system that is unaffected by clouds. An active microwave system might be required to provide all data of a given area in times of severe cloud cover to meet a given time schedule for inventory. It is likely, however, that most often such a system would be employed to assist in the extrapolation of information collected and analyzed in land

use/land cover in the visible and near-infrared region from cloud-free areas to cloud-covered areas.

The development of change detection techniques for the monitoring of residential expansion in the urban fringe zone is a requirement that is mandated to the U.S. Bureau of Census. The delineation of this urban fringe zone is used as a basis for the distribution of monies to local governments from a number of federal funding programs. As stated above, as naturally-developed and culturally-derived patterns typically produce shapes of different types, boundary delineation could potentially be assisted by the addition of an active microwave data component. Accuracy improvement derived through the addition of such a system, however, needs to be assessed.

The monitoring of the conversion of agricultural lands to urban development is of considerable interest to the resource manager. Conventional Landsat multispectral classification has limitations due to the similarities in spectral signatures of residential areas and certain agricultural practices.

Intra-urban land use category classification could be improved through the introduction of a texture component to the classification scheme.

Improved identification and inventory techniques are needed to map surface strip mines in the eastern and western regions of the United States. This information is required on both the federal and state level. Landform identification and terrain analysis are required as input to the area strip mining data bases. The ability to evaluate the excavation and reclamation activities over a large geographic area is also a data user need.

Abandoned mine lands identification and reclamation require the ability to identify altered surface topography, such as contour mining and mountain removal, through regrown vegetative ground cover. This requires a surface texture element in the spectral classifier. The federal government is placing a tax on each ton of coal to provide a multimillion dollar fund for the reclamation of the abandoned mine lands.

Species level information is needed for the wildland vegetated areas of the western U.S. and Alaska. These resources cover thousands of square kilometers and constitute a wildlife habitat resource that is inadequately mapped to date.

Forested wetlands identification and mapping require the delineation of basic species level data: deciduous, coniferous, and mixed. Surface texture data could provide additional information related to height and density of vegetation as associated with varying water regimes and, therefore, enhance the accuracy of delineating forested wetlands and harvestable timberlands of the coastal flatlands. Accurate delineation of coastal wetland boundaries hinges on the ability of radar to penetrate vegetation cover (marsh or floating aquatic plants) and then indicate whether the underlying surface is land or water.

Existing techniques of marsh productivity estimation provide for delineation of different species of marsh grasses, but fail to detect the inundating standing water beneath the marsh grasses. The inundating water boundary is a signficant parameter that affects marsh productivity. Microwave data may provide the boundary of wet and dry marsh and thereby lead to a more accurate estimate of the productivity of marsh grass areas.

Frequent surveys of a disaster site are required for satisfactory estimation of the intensity or extent of damage. This requires the ability to monitor the site through cloud cover, dense smoke, and at night. Such phenomona as tornados, hurricanes, floods, forest and range fire damage, and coastal shoreline overwash by storm surge waves require monitoring.

POTENTIAL

The accuracy of information to be extracted from the microwave measurement remains to be determined, but the potential to derive new perspectives on land resources applications remains. Particularly important here is the potential for radar to add an important spectral/textural component to land cover identification and to increase the potential for timely comprehensive mapping of land cover in areas of cloud cover by either direct or indirect means, assisting in the extrapolation of data from cloud-free to obscured areas.

Timeliness - With free-flying SAR sensors, data collection can be made independent of lighting and meteorological constraints. For land use/land cover applications, this means that user agencies can (a) obtain an immediate disaster assessment, and (b) depend on a remotely sensed inventory at specific dates. An example of (a) would be the assessment of the extent and location of flooding or building destruction for disaster relief. Examples of (b) are all the data being collected for government planning required at specific predetermined times. For land cover data to be efficiently integrated to the data base, it must also be available from that date.

Visual interpretation of image data - The extended information of SAR data may help improve the recognition of important land uses and delineation of the extent of land use/land cover types. Examples in urban areas include:

a. urbanized area boundary delineation,
b. discriminating strip commercial areas,
c. delineating transportation corridors.

Examples in rural areas include:

a. settlement patterns,
b. wind breaks,
c. abandoned strip mine pits.

Extended information content in automated pattern recognition procedures - Land cover mapping using pattern recognition techniques, particularly for some USGS Level II classifications, is going to require spectral information channels that are more discriminating than those on Landsat 1-3 and D, or even that envisioned for MRS. The surface roughness measurements and volume scattering properties available from SAR will help to more precisely identify man-made land use types. An example in urban areas includes: strip commercial transportation corridors. Examples in rural areas include: wetlands vegetation, irrigated lands, primary/secondary forests.

Independent machine processable land cover mapping from multi-channel and multipolarization digital imagery - A system which can provide the equivalent of MSS imagery for land cover mapping over large areas with no cloudiness constraint would permit timely inventories of large areas in moderate and heavy cloud cover regions. Envisioned here is an independent system calibrated with multispectral image classification results. Examples include:

a. Land cover mapping in humid tropical regions.
b. Annual regional and statewide inventories in the midwestern U.S.

RESEARCH NEEDS

The land use/land cover research needs for SAR applications will require an assessment of system capabilities, the impact of regional differences, and the ability to achieve specific classification accuracies.

Four kinds of system capabilities investigations need to be performed in a phased approach within each of the principal regions of interest in the U.S. The required investigations include:

Ground-based versus airborne versus spaceborne active microwave data - One of the more scientifically controllable and cost-effective methods of obtaining data pertaining to the backscatter coefficient of active microwave remote sensors is to use ground-based and aircraft scatterometers.

However, because the data collected are essentially for point targets or for small areal targets, the question often arises concerning the relationship of these data to the data obtained from both airborne and spaceborne imaging systems. The relationship of the University of Kansas spectrometer data of agricultural features and the snow pack data obtained by the Goddard Space Flight Center to airborne image interpretation (visual and mechanical) are cases in point. Similarily, the relationship between airborne image data and spaceborne synthetic aperture radar image data has not been defined. Because these questions are unanswered, it is imperative that they be asked and resolved with a systematic investigation.

Investigation of the impact of radar system parameters on land use and land cover signatures - In order to properly identify the parameters for optimum design of a radar system for data collection for land use/land cover applications, systematic studies need to be conducted to provide for the maximum combination of candidate parameters. The combinations can be thought of as an n-dimensional matrix composed of:

a. different land cover/land use types of interest,
b. look direction (azimuth),
c. wavelength,
d. resolution,
e. polarization,
f. depression angle.

Although some of the questions may be answered through analysis of engineering data, such analyses should be confirmed with empirical evidence. Such studies should be oriented not only toward defining an optimum radar system for land cover/land use studies, but also to determine how the backscattered signal may change through time for a given combination of items identified above, e.g., to determine how sensitive or insensitive the radar may be to subtle changes in the land cover.

Finally, because in any given geographical area the orientation of cultural features will not all be such that they will provide optimum image data, a detailed investigation should be initiated to determine the feasibility and methodology to be used to mitigate the look direction effects of the radar data.

Assessment of cartographic properties and planimetric accuracy of SAR - A need common to all land applications of SAR data is the geometric rectification of Level I data to ground coordinate systems. Ultimately, most information obtained from SAR data will be related to surface data or displayed in map format. In addition, geometric rectification is a necessary step if the SAR data are to be merged with complementary multispectral data (e.g., Landsat).

At a minimum, an experiment should be performed to determine the feasibility of SAR image data to meet National Map Accuracy Standards at a scale of at least 1:250,000 and preferably 1:100,000. Test sites should include flat terrain (e.g., Garden City, Kansas), undulating terrain (e.g., Washington, D.C.), and mountainous terrain (e.g., Whittier-Portage, Alaska). For each site, local as well as global, map accuracy needs to be achieved if the SAR and Landsat data are to be input to digital classification algorithms. This will probably require a systematic analysis and programming effort to utilize digital terrain files to assist in compensating for horizontal offset caused by look angle, and to assist in providing an understanding of the limits inherent in modelled topography compensation procedures.

Simultaneous multi-parameter SAR investigations - In order for SAR to conclusively demonstrate its ability to enhance the information content already existing for current and planned visible and near-infrared imaging sensors, simultaneous multi-parameter radar overflights need to be undertaken. Empirical studies of the backscatter properties of SAR over large areas from digital image data sets need to be undertaken to answer fundamental questions regarding the utility of SAR for three levels of remote sensing information enhancement. At least four simultaneous image data sets (multi-channel, multipolarized) need to be assessed for their enhanced information content to visual interpretation of image data. Similar data sets need to be generated for their systematic introduction to existing multispectral imagery to determine their contribution to improving automated pattern recognition of land cover/land use types. Finally, it should be demonstrated that it is possible to independently use multi-parameter SAR data to generate machine processed land cover maps.

While it is recognized that a comprehensive capability will not be achieved for some time, it will be necessary to undertake a sufficient number of experiments at enough test sites to assure that SAR imagery can provide sufficient information to meet the USGS Level II classification standards within each of the principal ecoregions of the U.S. Within each ecoregion it is important to investigate the land cover mapping and land use type recognition capabilities for SAR in three types of land use groups. In order of their significance, these are, first, metropolitan regions; second, cultivated rural lands; and third, wildlands.

RECOMMENDATIONS

The Land Cover Panel believes that several important resource application areas have been identified that could benefit from utilizing SAR data in the mapping scheme. The panel recommends that NASA develop a series of experiments in accordance with the guidelines expressed in the Research Needs section, which would provide a quantitative evaluation of the potential application areas identified in this report. Additional recommendations are:

1. Distribute Seasat-A data to a wider user community.
2. Develop a spaceborne SAR program as a means of continuing to furnish microwave image data compatible with Landsat D data.
3. Support the development and evaluation of MSS and SAR data integration and thematic classification techniques for land cover/resource mapping.
4. Evaluate multi-channel and multipolarization imagery for its potential improvement to land cover mapping over single channel SAR data.

WATER, ICE, AND SNOW

STATE OF KNOWLEDGE

Sea, Lake, and River Ice

Synthetic Aperture Radar - Numerous aircraft flights using active microwave imaging systems, as well as the limited ice data currently available from Seasat, have shown that SAR is a useful tool in examining floating ice problems. SAR imagery provides a map of the roughness of the ice and sea surface. As such, it allows delineation of the edge of the pack; specification of the lead systems which offer easy transit to shipping; identification of significant ice hazards (ice islands, large pressure ridges, floe bergs, ice bergs); precise specification of relative motions within the pack; and the ability to discriminate between first year and multiyear ice.

The improved knowledge of the motion field of the pack will provide individuals currently working on developing numerical models for simulating ice pack dynamics and thermodynamics with a data set against which different models can be tested and validated. Once such validations are completed, these models can be used with increased confidence in forecasting local ice conditions such as those along the North Slope during the operation of the Sea Lift. They can also be used in forecasts of the general motion of the pack in the Arctic Ocean and its peripheral seas. One of the many possible results of such modeling is an improved capability for predicting the level and location of under-

water sound sources in the Polar Oceans, a subject of great interest to the U.S. Navy.

Studies via the use of SAR of the air-ocean-ice interactions at the edge of the ice pack are, as mentioned, of considerable meteorological and climatological interest as this is an area of intense and complex interactions. The fact that SAR also provides information on wave direction and period is also a great help in the study of ice edge problems. SAR offers the potential of similar applications to lake and river ice problems, although the imagery is more difficult to interpret (it actually contains more information in that both volume scattering within the ice and the roughness of the bottom as well as the top surface affect the strength of the return). The positions of ice on the Great Lakes and the locations of ice jams on larger rivers should be clearly visible.

Scatterometry provides an important addition to SAR imagery in that it allows the direct determination of water-ice boundaries, the discrimination between multiyear and first year ice and information on the surface roughness of the ice. It is quite possible that correlations can be developed between the nature of the scatterometer return and the ridge height distribution. Scatterometry also permits ice type differentiation in both lake and river ice, although little work has been performed on this subject.

Radar Altimetry is also of use in studying the roughness characteristics of ice covers in that it measures the mean height of the ice, the roughness, and the total mean surface slope. Although scatterometry also has some potential application in this regard, it should be possible to translate the radar altimetry information into information on the number of pressure ridges and their height distribution. This is, of course, important to a wide variety of problems, for instance, vehicle routing problems over sea ice; submarine routing problems under sea ice; estimates of underwater sound attenuation produced by sound scattering by ridge keels; and estimates of the aerodynamic surface drag coefficient of the upper ice surface and the hydrodynamic surface drag coefficient of the lower ice surface.

In summary, active microwave remote sensing systems show great proven capabilities as applied to the remote sensing of sea, lake and river ice. They are believed to be the most important systems for such applications in that they combine high resolution plus all weather capability. Their operational potential can, of course, be enhanced via the simultaneous use of additional sensors. Of particular use would be thermal infrared systems which allow the determination of surface temperatures, and passive microwave systems which would facilitate the discrimination between ice and water and between types of first year ice.

Glaciers

Measurements made from the GEOS series of satellites and from Seasat have confirmed the feasibility of making precise determinations of the elevation of the surfaces of glaciers and ice sheets from a satellite platform.

The determination of the bed of a glacier and the sensing of internal features within glaciers is also an established airborne remote sensing procedure via the use of low frequency (10-60 MHz) radio-echo sounding. The possibility of expediting similar techniques via a satellite still remains to be explored.

Snow

Pioneering microwave measurements of snow were conducted in the 1950's and early 1960's. Since that time considerable progress has been made both in accuracy and precision of the sensors and in the understanding of the interaction mechanisms. An important associated item has been the recognition of the need for parallel detailed ground truth for improved understanding of the microwave data.

Table 6 is a summary of past microwave measurement programs of snow, concentrating on active measurements, but also listing associated passive microwave studies. Frequency and angle of incidence at which the measurements have been made are noted.

The most recent and comprehensive measurements of snow properties using active microwave techniques have been made by investigators at the University of Kansas. They found that snow water equivalent causes the radar scattering coefficient, σ_o, to increase at angles away from nadir. Free water content, on the other hand, causes σ_o to decrease at angles away from nadir. The sensitivity of σ_o to free water content generally increases with both increasing frequencies and increasing angle of incidence. The variation of σ_o with free water content becomes increasingly nonlinear with increasing frequency. The variation of σ_o with snow water equivalent was observed to be exponential. Snow surface roughness exhibits a small effect on σ_o under dry snow conditions and a large effect under wet conditions. A simple model for incorporating the effects of snow wetness, snow water equivalent, and soil state (frozen or thawed) was shown to give a good representation of σ_o in terms of measured ground truth values.

Hydrology

Microwave sensors appear to be capable of measuring the four characteristics of a watershed that control the amount and rate of runoff from rainfall: soil moisture, vegetation, soil structure, and surface roughness. These characteristics have not been measurable previously as direct input to hydrologic prediction and forecast models. Currently, there are no adequate models to use this type of information, even if it were measured on a routine basis. This, in addition to the capability of measuring areas instead of points, may be important contributions to future hydrologic procedures. Microwave sensors also have the all weather capability necessary for hydrologic applications.

Soil Wetness

Present evidence shows that both active and passive microwave respond to soil moisture variations in the upper surface. In fact, correlations of microwave data with gravimetrically determined soil moisture approach the limit imposed by the accuracy of the ground truth measurements. This is in the case of homogenous bare surface conditions. The perturbing factors superimposed on this which arise from changes in roughness, soil type, slope, vegetation cover, and shape of the moisture profile with depth, degrade the sensitivity and accuracy of the measurement, but do not appear to preclude making acceptable moisture estimates. Individual studies of each effect and its consequent effect on sensitivity and accuracy, have been performed. However, the data base is not yet sufficient to perform statistical analyses of combined effects. The relative response of microwave sensor data to soil moisture in the upper surface is reasonably well documented.

There is not the same degree of agreement with regard to what is the absolute measurement accuracy obtainable, or even what absolute measurement accuracy is required. For instance, the moisture profile with depth is a continuously varying function. The expression of percent soil moisture immediately implies an average composition over some depth interval. The microwave measurement of the moisture is a nonlinear weighted response to moisture in the profile. In general, the response decreases exponentially from the surface with the rate of decrease a function of the moisture present and the sensing wavelength. With this the case, correlation analyses of microwave response versus moisture from different depth intervals can be quite misleading due to the high degree of internal correlation of moisture between differing depth intervals.

APPLICATIONS

It is clear that active microwave remote sensing systems can provide useful data for the study of surface water supplies, ice and snow relative to the dynamics of the

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OF POOR QUALITY

TABLE 6.
Summary of Microwave Measurement Programs of Snow

TYPE OF MEASUREMENT	ORGANIZATION	YEAR	FREQUENCY	ANGLE OF INCIDENCE	REFERENCE
Reflection Coefficient	National Research Council, Canada	1952	9.375 GHz	40-88	Cumming (1952)
Reflection Coefficient	Japan	1958	4 GHz	88	Suzuki and Hasegawa (1958)
Reflection Coefficient	Naval Ordinance Laboratory	1966	35.26 GHz	22.5	Battles and Crane (1966)
Snow Stratigraphy--Short Pulse	Colorado State University	1972	[illegible] GHz	0	Vickers and Rose (1972)
Snow Stratigraphy--FM-CW	Canadian Communication Research Center	1973	8-12 GHz	0	Venier and Cross (1972)
Snow Stratigraphy--FM-CW	National Bureau of Standards	1977	8-12 GHz	0	Ellerbruch, et al. (1977)
Backscatter	Sandia Laboratories	1959	3.8 GHz	0-30	Janza, et al. (1959)
Backscatter	Ohio State University	1960	10, 15.5 and 35 GHz	10-80	Cosgriff, et al. (1960)
Backscatter	University of Alaska	1972	35 GHz	0-70	Seckinger (1972)
Backscatter	Cold Regions Res. and Eng. Lab.	1972	10, 35 and 95 GHz	89	Hoekstra and Spangole (1972)
Backscatter	Georgia Institute of Technology	1977	35 and 95 GHz	75-82	Currie, et al. (1977)
Backscatter	Rome Air Development Center	1978?	35, 98 and 145 GHz	0-75	Hayes, et al. (1979)
Backscatter	University of Kansas	1975	1-8 GHz	0-70	Ulaby, et al. (1977)
Backscatter	University of Kansas	1977	1-18 and 35 GHz	0-70	Stiles, et al. (1977)
Imagery (AN/APQ97)	University of Kansas	1970	35 GHz	-----	Waite and MacDonald (1970)
SKYLAB S-193 Scatterometer	University of Kansas	1975	13.9 GHz	5	Eagleman, et al. (1975)
Apparent Temperature	Aerojet General Corp.	1965 to 1971	1.4, 6, 13.4 and 37 GHz	-----	Edgerton, et al. (1971)
Apparent Temperature	University of Berne	1977	4.9, 10.5, 21, 35 and 95 GHz	0-65	Schanda and Hofer (1977)
Apparent Temperature	University of Berne	1978	4.9, 10.5, 21, 35, and 95 GHz	0-65	Matzler, et al. (1979)
Apparent Temperature	Helsinki University of Technology	1978	4.8 and 36.8 GHz	0-70	Tiuri, et al. (1978)
Apparent Temperature	NASA Goddard	1971	1.4, 2.7, 5, 10.7, 19.3 and 37 GHz	45	Schmugge, et al. (1974)
Apparent Temperature	NASA Goddard	1977	1.4, 17.6, 21.4 and 37 GHz	48	Hall, et al. (1978)
Apparent Temperature	NASA Goddard	1978	5, 10.7, 18, and 37 GHz	0-85	Shiue, et al. (1978)
ESMR/Nimbus 5	NASA Goddard	1973	19.35 GHz	50	Gloersen and Salomonson (1975)
ESMR/Nimbus 5,6	NASA Goddard	1976	37 GHz	50	Rango, et al. (1976)
Nimbus-5	University of Berne/MIT	1973	22.2 and 31.4 GHz	0	Kunzi, et al. (1976)

hydrologic cycle and related climate, agricultural, and engineering problems. High resolution, active microwave imagery from space can immediately provide useful observations in several applications areas. Applicable observations for navigation and shipping operations troubled by ice cover on rivers and lakes and offshore operations in the Arctic and Sub-Arctic would be available--not only because of the high spatial resolution but also because of the ability to make observations through persistent cloud cover.

It is also clear that SAR imagery treated as an additional spectral band in combination with Landsat data would serve to better delineate land cover and associated changes in time that would be useful in watershed planning studies. The ability to acquire images through clouds and modest amounts of vegetation would also assist in obtaining timely flooded area surveys and marsh or wetland studies and surveys. Because of the demonstrated responsiveness of active microwave observations to moisture in snow and soil as well as varying spectral sensitivity to vegetation, soil structure, surface roughness (the watershed characteristics affecting and controlling the amount of runoff from precipitation), it is recognized that there is a considerable potential for utilizing and applying active microwave observations for a wide variety of fundamental hydrologic studies. This requires continued research to effectively understand and quantify this information.

Sea, Lake, and River Ice

Although there are many aspects of sea, lake and river ice that are different, in general the problems caused by these ice types are similar.

When sea, lake or river ice form they produce surface barriers to ship movement. The thickness of ice that can be transited depends, of course, upon the design characteristics of each given ship. However, even the most powerful ships can greatly speed their passage through ice by utilizing the flaws (leads) that are produced by differential ice movements. To less powerful ships, the use of such lead systems is absolutely essential to safe passage. When pack ice converges, the resulting friction exerted on a ship's side is enough to stop even the most powerful ship. Accurate estimates of how long such ships can be immobilized are crucial to ship routing and to the design of adequate storage facilities in northern developments.

Ice jams on large rivers such as the Mississippi and Ohio, terminate barge traffic, and commonly damage or destroy a number of barges each year. The economic losses associated with such curtailments of river traffic are estimated to be on the order of a million dollars a day. In addition, ice jams on numerous smaller rivers cause severe local flooding at a number of sites in the U.S. and Canada each year. Organizations concerned with such problems include the Corps of Engineers, U.S. Navy, U.S. Coast Guard, and a wide variety of organizations involved in developing sea transportation in the high Arctic and winter transportation within the inland water systems of the United States.

In addition, offshore operations for oil and gas are now underway at a number of sites in the Arctic and Sub-Arctic where ice related problems pose a serious hazard both as a major design consideration and as a continuing threat during operations. Detailed knowledge of sea ice behavior can greatly lessen the possibility of design or operational errors that would result in production delays and offshore spills. Such spills could be very difficult to control in the polar oceans as ice would at best impede and at worst prevent attempts to stop and clean up the spill. Considering that in Arctic Alaska such spills would be localized by the heavier ice to major marine mammal migration routes, the economic and political ramifications of such occurrences would be extreme. Data and increased capability relating to those

areas would be of great value to a variety of organizations within the U.S. Government (DOI, Corps of Engineers, U.S. Coast Guard, DOE), to the State of Alaska, to the Canadian Government, and to a number of oil and gas companies and their contractors that contemplate the development of such ice covered regions.

Probably the most important aspect of the world's floating ice covers are their effect on weather and on climate. The ice acts as an insulating layer between the cold air and the warm ocean. The amount of heat being transferred to the atmosphere is governed largely by the location of the pack and by the amount of diverging motion occurring within the pack (the percentage of leads or very thin ice areas). In addition, the edge of the ice pack is known to exert a significant steering effect on the large winter storms that form along the Gulf of Alaska and the Bering Sea and in the North Atlantic. Depending upon the location of the edge of the pack ice, these storm systems may take quite different routes resulting in appreciable changes in the weather in North America and Europe. Improved data and understanding of these subjects would be of great interest to NOAA, WMO, and to a variety of private organizations involved in meteorological forecasting.

Many scientists think that the Earth is currently in a period of climatic change and that in the coming decades the increase in atmosphere CO_2 will result in a general atmospheric warming. If this occurs, the greatest warming will probably be in the polar regions, with the most affected natural entities being the sea ice cover and the large glacier systems. For instance, initial estimates of possible climatic changes by the end of the century suggest the possibility of a 5°C warming during the polar summer. Under such conditions, the polar ice packs could completely disappear during the summer. The effects of such changes on world weather and on transportation routes could be enormous. If models of such future behavior of the world's floating ice sheets and the effects that changes in the present conditions would have on world weather can be developed, the results would be of great interest to climatologists and to persons involved in long-term economic and agricultural forecasts. Undoubtedly the climate of large regions would undergo appreciable changes. Such information would be invaluable to the National Climate Program, to NASA's Climate Program, and to the planning community in general.

Glaciers

There appear to be several applications of active microwave measurements to the study of ice caps and mountain glaciers. The basic data need in the case of ice caps, is an accurate map of the elevation of the upper and lower ice surfaces. The data would be used directly by the scientific community to address basic glaciological questions related to the ice caps. The determination of surface topography is essential to this research because the dynamic behavior of the ice caps is in part determined by the distribution of surface slope. Measurements of changes in the surface elevation of mountain glaciers would be particularly useful in the study of glacier surges; another area of current research activity. During a surge, the accumulation region of a glacier drops quickly, accompanied by a sudden advance of the glacier tongue.

The long term behavior of the ice caps is important because of their interaction with the global climate system. Even though the response time of the ice caps is of the order of 1,000 years, measurable change may occur on scales of years and decades. One important place to look for such changes in the total ice volume. Such changes have far-reaching importance for determining global climate and the mean sea level.

For mountain glaciers, the most promising applications seem to be determining water content of the snow, and in measuring the surface elevation. The economic significance of a proper understanding of the runoff from glaciers cannot be overestimated. The runoff affects fresh water supplies, hydroelectric generation, and recreational activities. For these reasons, the study of the behavior of melt water in a glacier is a topic of current research interest.

Snow

Probably the greatest needs of water resources users in the area of snowpack properties involve measurements of snow cover extent, water equivalent and/or depth, and free water content on an areal basis. These particular items have been shown to be especially important for the prediction of the quantity and timing of snowmelt runoff. In addition, the determination of the underlying soil conditions (most importantly frozen vs. unfrozen, but also dry vs. wet) has a major influence on the amount of runoff generated during snowmelt. Snow cover, depth, and frozen soil condition are determining factors for winter kill of wheat. All of these user information needs are of high priority and can potentially be met by remotely sensed data if the data are available in a timely fashion and on a frequent basis, usually within three days in most cases.

Conventional measurements commonly focus on the determination of snow depth and water equivalent, but only at a few specific points in a basin. The area-wide measurement of all of the above parameters is, generally, not satisfied with existing data sources.

Hydrology

There are a number of hydrologic applications that potentially can be met by remotely sensed data. In general, the usable design and planning procedures have not changed in the last 20-40 years, in spite of computers and considerable research directed towards describing hydrologic processes in great detail. One of the major reasons the new research has not been adopted by agencies and engineering firms is because of the very complex and numerous data needs. The major hydrologic applications that could be met with improved data are flood and water supply forecasting and hydrologic evaluation of land use changes caused by urban development, agriculture, mining, etc. Major benefits would be realized by developing procedures to use physically-based distributed models or by developing measurable hydrologic coefficients for lumped models. This includes one time or several sets of data (spaced months or years apart) to describe drainage network, topography, soil type and land use. It also includes data on the state of the system that would be available at frequent intervals (hours or days) to describe soil moisture, snow, frost, and precipitation distribution. The temporal data would be invaluable for forecasting and for feedback to large scale water management simulation models.

The user community for such information includes all federal and state agencies dealing with water resources, as well as private engineering firms, irrigation companies, and the power industry. The economic benefits can be estimated because water has a price, and the effects of too much water or too little water can be economically determined. The lack of suitable structural alternatives (i.e., dams, levees, etc.) and their environmental consequences makes it imperative that future benefits be realized through improved forecasting and management.

Soil Wetness

There is a large and growing demand by agriculturalists and hydrologists for an accurate, synoptic measure of the volume of water present in the soil at any given time. The terms soil wetness and soil moisture are used to label the desired measurement for hydrology and agriculture applications, respectively. Different terms are used because each application area has somewhat different requirements for accuracy, scale, frequency of measurement, etc. The information needs, stated broadly, are:

1. Hydrology - determination of upper zone soil wetness for determination of infiltration and percolation.

2. Agriculture - determination of root zone soil moisture as an input to vegetative growth and production models.

While a host of applications making use of soil wet-

ness/soil moisture profile data could be listed, the highest priority in terms of economic benefit are associated with:

1. Determination of runoff for stream flow forecasting.
2. Improvement of crop yield forecasting.

While there is virtually unanimous agreement as to the benefit that soil wetness/soil moisture data would provide to these two applications, the specific data needs are not well defined. This is due to the absence of any directly competing data source. In most current forecast models, the moisture response is incorporated through meteorological data inputs into empirical relations. This means that development of the application must focus not only on the ability to perform the measurement, but on modifications of existing technology and techniques to accept inputs in this form.

POTENTIAL

Sea, Lake, and River Ice

Active microwave systems have a unique capability for studies of floating ice masses. To be specific, they are capable of providing high resolution information at all times of the year regardless of the weather (clouds or fog) or the light conditions (the long Polar night). This capability is absolutely essential for floating ice problems in that most difficulties and major ice movements occur either during storms or during the winter months when light is limited. Even during the summer the areas of pack ice are invariably shrouded in fog.

The advantages of the different microwave techniques as applied to different specific ice problems are described elsewhere in this report. It should be noted that although the active microwave sensors have undoubtedly the greatest potential application to ice problems, their usefulness is greatly enhanced by simultaneous data collected by passive microwave systems, multispectral scanners, or laser systems.

Glaciers

The need for measurements of the surface elevation of the ice caps and glaciers cannot be satisfied by visual or infrared remote sensing techniques. There is every reason to believe that a radar altimeter will provide elevation measurements of sufficient accuracy. Whether or not the bottom surface can be adequately profiled from space remains a moot point.

In the study of mountain glaciers, microwave backscatter has the potential to resolve the amount of liquid water on the surface. It is anticipated that visual imagery and perhaps infrared sensor data would be used with the microwave data to determine the shape and exposure of the glaciers.

Snow

All of the user needs for snow information most likely require an approach to measurement that would combine various types of remote sensing data. The fact that microwave energy penetrates the snowpack (and soil) surface provides a significant advantage over visible and thermal infrared techniques. Snow cover extent is best measured with visible data except under cloudy conditions when microwave sensors could provide back up support. A multispectral microwave approach to measuring snow depth and water equivalent is possible because of the different penetration depths for the various wavelengths. The detection and measurement of free water content is also amenable to microwave (in both active and passive). The detection of frozen ground with microwave sensors based on changing dielectric properties, has been demonstrated and is possible even beneath a snow cover, when sufficiently long wavelengths are employed.

For runoff forecasting, the logical combination is that of snow cover extent determined by visible techniques and snow depth and water equivalent determined by microwave techniques. The combination of these results is the total snow volume available for snowmelt runoff. Combination of both active and passive microwave techniques appears necessary for optimum results.

Hydrology

Water resource needs that can be best met by microwave data are primarily those related to the correction of temporal data. One of the most important requirements is for all weather capability. An equally important requirement is for repetitive measurement of the watershed state variables: soil moisture, forest, snow, and perhaps cover conditions in agricultural areas.

The ability of microwave energy to penetrate vegetation (or not penetrate depending on frequency, polarization, and angle), to respond to soil structure, to respond to surface roughness, and to respond to soil moisture, are perhaps the most important features for hydrologic applications. These are the four watershed features that affect runoff from rainfall. In the existing hydrologic procedures, these features are seldom measured directly but are estimated according to arbitrary relative scales. The potential for measuring the features directly could be a significant breakthrough for improving hydrologic techniques.

Remotely sensed data have an additional feature that potentially has great benefit for the water resource community; that is the ability to measure an area, rather than a point. Hydrologic concepts have been developed from point measurements, i.e., soil columns, rain gauges, etc. As a result of this, hydrologists have been largely unsuccessful in treating spatial variability. This is perhaps the single most important reason why infiltration theory has not been successfully adapted for hydrologic procedures.

Remote sensing has the potential for "averaging" a great deal of information over an area. Use of these types of data may provide the motivation for using more physically based models. However, it is likely that such models will have to be adapted or new models developed to take advantage of these data.

Other types of measurements, MSS, IR, etc., could provide invaluable additional information to any single areal measurement. These other wavelengths would in general augment the microwave data; the microwave data being the primary requirement for hydrology.

Soil Wetness

The unique aspects of microwave sensing of soil wetness can be summarized in two words; timeliness and penetration. The timeliness is a result of the near independence of microwave data on atmospheric effects and solar illumination. The penetration is due to the long wavelength of microwave energy and resultant increased skin depth.

Penetration of a significant depth of moist material is what give rise to the unique potential for microwave data. Visual or infrared sensors have been shown to also give a significant response to soil wetness, however, this response is confined to the uppermost few molecular layers of the surface. Near saturated conditions, these surface effects may be quite striking. With only this thin surface film to work with, there is no way to integrate the total moisture input to the soil profile. Likewise there is no way to determine drying rates after the formation of a dry surface layer. On the other hand, the microwave signal is a composite of a far deeper section, variously estimated from 2 cm to 30 cm depending on moisture profile conditions.

In the case of moisture input, this increased depth penetration provides the integration and storage needed to determine the size of the input event. In the drying cycle, monitoring of the response with time provides information on evaporative demand. This ability to account for total input and output is essential to developing water budget models to forecast the moisture content to still greater depths, such as required in crop forecast models.

Other sensors will offer considerable aid in performance of these general tasks. For instance, knowledge of type and amount of vegetative cover will improve moisture esti-

mates. This information may be obtained either from visual/infrared sensors or by incorporating diversity in the microwave sensors. That is, this identification may also be made using microwave sensors, but the system operating parameters will be distinctly different from those of the moisture measuring instruments.

It also appears desirable to consider acquisition of both active and passive microwave data optimized for moisture measurement. The active instrument will be needed to provide spatial resolution compatible with the various applications. Passive microwave sensors provide information in a different portion of the angular scattering pattern which may improve moisture estimation and may offer the capability of increased sensing depth.

RESEARCH NEEDS

Sea, Lake, and River Ice

1. Procedures for rapidly and accurately obtaining ice velocities, strains, and strain rates should be developed using Seasat SAR data of sea ice regions. Also, consideration should be given to automating pattern recognition techniques for determining quantitative information on ridging and lead patterns, and floe geometry.

2. The data derived from the above program should be used in several alternate ice dynamics models both as input and as adequacy checks on the ultimate model forecasts. Studies should be made using detailed models specifically tailored for certain regions or seasons, as well as basin-wide models. The use of SAR imagery in such studies should greatly increase the confidence in the predictive capabilities of such models.

3. Work should be expanded to improve the understanding of variations in the radar scattering coefficient, σ_o, of sea ice. Ice of a variety of different temperatures, brine volumes (salinities), and crystal orientations should be studied. Studies should also be made of the σ_o of pack ice as a function of the degree of surface ridging and the look angle. This will require the simultaneous operation of a calibrated radar system and an airborne laser profilometer.

4. Altimeter measurements should be made of the character of radar return from sea ice of varying roughnesses. The possibility of making predictions of the roughness of the underside of the ice from the altimetry data should also be examined. It would undoubtedly be profitable to further explore the physics of the scattering from rough ice surfaces. As an additional facet of this program, attention should be given to the possibility of determining the aerodynamic roughness of ice surfaces using scatterometer and radar altimeter data.

5. Experiments should be carried out that expand the ability and confidence to interpret SAR imagery from the marginal ice zone (a region where ice types may vary significantly from locations further into the ice pack). SAR data would also be useful in expanding the knowledge of mixing processes across the ice front.

Glaciers

While the principle of precise satellite altimetry seems sound, research is needed to define an optimal system for use over glacier ice, or at least to be certain that a multipurpose sensor will give satisfactory results over ice. This will require collaboration between the remote sensing and glaciological communities. Minimum ultimate specifications for the system must be:

1. vertical absolute accuracy of $\pm$ 1m.
2. horizontal absolute accuracy of $\pm$ 100m.
3. foot print of less than 100m x 100m.
4. linear sampling.
5. good coverage of the ice caps once per year for many years.

The potential application of microwave sensing to determine the water content of snow deserves continued study. Again, coordination is needed between the glaciological and remote sensing communities to make progress toward this goal. The possibility of determining from space the bottom topography of glaciers and ice sheets should be further explored.

Snow

Only a few well planned experiments for the active microwave sensing of snowpack properties and frozen soil have been conducted. More data are needed. Specifically, a variety of differing snow types have to be studied. Particularly, simple models relating σ_o and apparent brightness temperature to snow properties have been developed which in order to be tested adequately and improved, require well planned ground-based and aircraft programs under a variety of environmental conditions. Calibrated SAR imagery is required to begin to extend active microwave measurements on an areal basis. Calibration could be facilitated by use of truck data or aircraft scatterometer measurements.

The following specific items should be addressed in the experiments:

1. Better understanding of the dielectric properties of snow, especially the imaginary part (effect of wetness and crystalline structure have yet to be measured between 8 and 35 GHz).

2. Attenuation and penetration depths need to be better quantified for different wetness and crystal size conditions.

3. Varying crystal size effects on σ_o have to be quantified.

4. The σ_o response to snow water equivalent and depth under widely varying natural conditions needs to be established.

5. The surface roughness effects of wet snow need more detailed study.

6. Fading statistics for both intrafield and interfield variations need investigation.

Hydrology

1. Determine the hydrologic significance of microwave measurements as affected by vegetation, soil type, roughness, and soil moisture.

2. Develop procedures to extract direct measurements of these four factors from remotely sensed microwave data, or develop a hydrologic equivalent that encompasses all four factors.

3. Investigate the size of hydrologically homogeneous areas that can be represented by single measurements.

4. Determine the scale of hydrologic units that can be lumped with predictable losses in sensitivity.

5. Investigate the possibility of measuring rainfall input to hydrologic areas with SAR. Two issues should be addressed:

   a. Determine effective isohyetal maps of rainfall input to large areas for water balance calculations (agriculture yield, drought, and water resource management).

   b. Determine if real-time estimates of rainfall rates and/or amounts can be estimated for real-time flood forecasting.

6. Investigate the use of SAR in groundwater resource management. Three items should be addressed:

   a. Identification of groundwater recharge and discharge areas for general planning, as well as solid and liquid waste disposal.

   b. Resource inventory including springs and seasonal changes in groundwater elevation.

   c. Procedures for conjunctive management of surface and subsurface water.

Soil Wetness

1. Determine depth profile of moisture that can be related directly to the microwave response.

2. Establish and test moisture budget models operating with microwave and meterological inputs that can extend estimates of soil moisture to root zone depths.

3. Improve definition of perturbing effects on sensitivity and accuracy of moisture measurement. These include effects of roughness, soil type, vegetation cover (type,

density, volume, moisture content, etc.), moisture profile, slope, and diurnal variations.

4. Improve definition of combinations of perturbing effects. This includes defining their spatial distribution and likelihood of occurrence as well as their combined effect on the microwave response. By implication, this need requires immediate movement to incorporate imaging systems into the moisture measurement program. Although it is commonly acknowledged that the ultimate spaceborne system must have an imaging format, no current effort is being spent in imagery analysis other than in a few Seasat experiments. Most current research is engaged in interpretation of truck and airborne system data.

5. Improve definition of soil moisture relation to infiltration capacity and consequent runoff. This also must be performed under the combined effect of the perturbations listed above. Perform runoff experiments using integrated microwave measurements obtained from imaging systems.

6. For both the agricultural and hydrologic applications, there must be definition of the spatial resolution/aggregation requirements in the presence of perturbing effects such as those listed, with the addition of such things as land use patterns, urbanizations, etc.

RECOMMENDATIONS

Sea, Lake, and River Ice

1. A suitable dialogue should be developed with different elements of industry to enable a number of applied experiments using SAR to be developed. Examples might be ship routing studies involving the Coast Guard, polar resupply vessels, or members of the Alaskan fishing industry. Other possibilities are the application of detailed ice movement or ice forecasting studies to offshore construction north of Prudhoe Bay.

2. Consideration must also be given to processing SAR imagery more rapidly and in a map-correct format that facilitates its further analysis. Any system that produces large amounts of imagery must also be geared up to process large amounts of imagery. Also, models must be developed that gain maximum utilization from the specific products of SAR.

3. Thought must also be given to the efficient use of other types of imagery and data in conjunction with the active microwave data. There are many possibilities which can undoubtedly be tailored to fit the specific problem under study.

Glaciers

It is recommended that NASA undertake to demonstrate the applicability of satellite radar altimetry to precise mapping of the Greenland and Antarctic ice sheets. Specific short term objectives should be:

1. To solicit interest from the glaciological community.
2. To support a study of existing technology by a small group of glaciologists and remote sensing specialists focused sharply on this issue.

Long-range objectives should be:

1. To maintain the capability for making these observations.
2. To support the data processing effort required to interpret the altimetry measurements.

It is further recommended that NASA continue to encourage research on the microwave properties of wet snow. The short term objectives here are to broaden the understanding of this phenomenon so that suitable techniques can be developed for making satellite observations of the melting glacial surface. It is emphasized that collaboration with the glaciological community is essential. Important questions to be resolved are: how to distinguish different surface types such as glacier ice, melt water, firn, and new snow; with what precision can the wetness of snow be determined; and are the results sensitive to fog, or other meteorological conditions?

The measurement of the surface topography of the major ice caps appears to be within the range of present technology and is of the first importance. Application of microwave sensing to determine the runoff from mountain glaciers seems less likely to pay off in the short term.

Snow

Several experiments must be performed to satisfy the previously mentioned research needs.

1. Dielectric constant measurement of snow with differing properties should be made in an environmental chamber under the range of parameters shown in Table 7.

2. For all experiments, better ground truth of the snowpack and the underlying target is needed to facilitate model improvement and implementation. Table 8 lists the needed ground truth parameters.

3. Snow wetness should be measured at various depths (Table 8) to correlate with the varying microwave penetration depths at different frequencies. More frequent sensor and ground truth measurements should be made when snow wetness changes are occurring.

4. A coordinated effort should be mounted to obtain a series of ground-based active measurements over widely varying snow depth and crystal size conditions. Measurements of σ^0 and ground truth should be conducted at several sites such that at least the following conditions are included:

Table 7. DESIRED RANGE OF PARAMETERS FOR DETERMINING DIELECTRIC PROPERTIES OF SNOW

PARAMETER	
FREQUENCY	1-18, 35, 95 GHz
DENSITY	.1 TO .5 g/cm^3
WETNESS (FREE WATER CONTENT BY VOLUME)	0 TO 15 %
CRYSTAL SIZE	.2 mm TO 1 cm
TEMPERATURE	-20°C TO 0°C

Table 8. GROUND TRUTH PARAMETERS

A. SNOWPACK PARAMETERS:
   1. DEPTH & STRATIFICATION
   2. DENSITY PROFILE BY LAYER
   3. WATER EQUIVALENT BY LAYER
   4. WETNESS PROFILE 0-1 cm, 1-2 cm, 2-5 cm, 5-15 cm, ETC.
   5. TEMPERATURE PROFILE (2 cm INCREMENTS)
   6. CRYSTAL STRUCTURE (SHAPE AND SIZE)
   7. SURFACE ROUGHNESS (CLOSE-UP PHOTOGRAPH)

B. UNDERLYING SURFACE PARAMETERS:
   1. TYPE (SOIL, CONDITION-FROZEN, ETC.)
   2. MOISTURE CONTENT PROFILE (0-2 cm, 2-5 cm, 5-10 cm)
   3. TEMPERATURE PROFILE (DOWN TO 10 cm IN 2 cm INCREMENTS)
   4. SURFACE STRUCTURE (ROUGHNESS)

C. AUTOMATIC AND ENVIRONMENTAL PARAMETERS:
   1. AUTOMATIC PRESSURE
   2. AIR TEMPERATURE
   3. HUMIDITY
   4. INCIDENT SOLAR RADIATION
   5. REFLECTED SOLAR RADIATION
   6. CLOUD COVER CONDITIONS

snow depths ranging from less than 0.5m to greater than 3m; snow over frozen, thawed, wet, and dry soil. These experiments need to be conducted at a wide range of elevations with different snow accumulation rates and crystal sizes.

5. It is strongly recommended that passive microwave measurements be conducted simultaneously with the active measurements for (a) savings in cost of logistics, (b) savings in cost of ground truth acquisition, and (c) providing a means for evaluating the advantages of combined use of active and passive microwave sensors over either one alone.

6. Develop models relating microwave parameters to snowpack properties and use the modeling concepts to guide field experiments and data collection. Verify or modify models based on field data.

7. Conduct a comprehensive experiment over varying snow conditions that will involve ground-based and aircraft scatterometer measurements and calibrated aircraft multispectral SAR data. Evaluate the utility of SAR capabilities for measureing snowpack and underlying conditions of large areas.

Hydrology

To realize the potential of SAR or other remote sensing data for hydrologic applications, a concurrent development of the remote sensing capability and the development of modified or new hydrologic models will be required. The concurrent development is important because existing procedures cannot take full advantage of the information in remote sensing; especially the potential improvements available from SAR.

Studies should be initiated to determine the effects of scale of hydrologic parameters or features on the results of prediction models. A simulation approach should be initiated that will not be dependent upon specific remotely sensed data. The results of these studies should provide information on how to lump hydrologic parameters. Those studies will also give a first estimate of remote sensing resolution and revisit requirements.

Set up a series of field verification experiments that are carried out concurrently with the development of measurement capability and the development of models to use these data. The field experiments should be conducted in several areas of different land resources so that the final results can be generalized to other parts of the country. The field experiments should be conducted in highly instrumented research watersheds that can provide the necessary ground truth data. Periodic truck and aircraft remote sensing measurements should be made to meet specific research objectives.

Soil Wetness

1. Continue ground-based measurement programs to provide calibration data of microwave system response to both sensor and target parameter variations. This effort should not be only continued but expanded, since in many cases verification of potential applications must await long term data acquisition. For instance, snow pack monitoring or crop fore-casting experiments require dedication of the instrument to a local area for an extensive period of time. Extending the data base to different geographic and climatic regions as well as to address additional applications, requires more calibration-type systems.

2. Ground-based truck and airborne line-trace systems are both, essentially, calibration type instrumentation for development of inversion algorithms and understanding of the basic physical process. The effect of spatial variability must receive more attention. This requires the conduct of experiments utilizing imaging sensors, preferably in conjunction with the calibration instruments. Over this type spatial scale, the ground truth requirements developed for calibration sensors are obviously impractical. However, changes in response over broad regions must be discernible if there is to be an ultimate use.

3. Improve communications with the user community. In many instances there does not exist the means for utilizing soil moisture data in the form measured by microwave sensors. Unless parallel development of applications models utilizing microwave soil moisture input is done, there cannot be a realistic demand for these type data.

4. NASA should stop assigning such a large proportion of available resources to targets of opportunity. Concentrate on the fundamental applications wherein microwave sensor data have a potentially unique and valuable contribution.

CONCLUSION

The ERSAR Applications Working Group concentrated on identifying applications of remotely sensed data which could benefit from active microwave sensor data. Although most of the Working Group members were more experienced with the use of visible region sensor data than with microwave data, they also succeeded in providing a useful summary of the capabilities of active microwave sensor data, and of the research needed to satisfactorily verify these capabilities.

These facts will be used by the Program Definition Working Group during their January 23-25, 1980 workshop to structure a detailed plan for future research and development in microwave remote sensing.

APPENDIX A

ERSAR working group

ERSAR APPLICATIONS WORKSHOP
LUNAR AND PLANETARY INSTITUTE

Clear Lake, Texas
November 7-9, 1979

AGENDA

November 7

8:00 Registration

8:30 ERSAR Committee Structure and Objectives - S. Rasool, NASA Headquarters

8:45 Workshop Format and Objectives - Jack Estes, University of California

9:00 Workshop Organization and Logistics -
Jay Harnage, Johnson Space Center
Sue Sims, University of Missouri

9:15 Panel Briefings - Tony Lewis, Session Chairman, Oregon State University

Remote Sensing in Geology -
- P. J. Cannon, University of Alaska
- Paul Harrison, Cities Service Corporation
- Harold MacDonald, University of Arkansas
- Ronald Gelnett, Mars, Inc.

Remote Sensing in Agriculture -
- Chris Johannsen, University of Missouri
- Fawwaz Ulaby, University of Kansas
- Forrest Hall, NASA/Johnson Space Center

12:45 Lunch

2:00 Remote Sensing of Land Cover -
- John Place, USGS
- Chih-Tseng Wu, NASA/NSTL
- Nevin A. Bryant and M. Leonard Bryan, JPL

Remote Sensing of Water, Ice and Snow -
- Wilford Weeks, CRREL
- Albert Rango, NASA/Goddard Space Flight Center
- William P. Waite, University of Arkansas

5:00 Panel Organization - Tony Lewis

5:30 Social Hour

8:00 Panel Sessions & Steering Committee Meeting

November 8

8:30 Summary of NASA Microwave Remote Sensing Projects -
James Taranik, NASA Headquarters

9:00 Panel Sessions

12:00 Lunch

1:30 Panel Summaries of Potential Applications - Jack Estes, Session Chairman
- Geology - Harold MacDonald, University of Arkansas
- Agriculture - Roger Hoffer, Purdue University
- Land Cover - Jerrold Christensen, Environmental Systems Research Institute
- Water, Ice, and Snow - Wilford Weeks, CRREL

2:30 Panel Sessions

5:00 Break for Dinner

5:00 Steering Committee Meeting

8:00 Panel Sessions

November 9

8:30 Panel Reports - S. Rasool, Session Chairman
- Geology - Paul Harrison
- Agriculture - Roger Hoffer
- Land Cover - Jerrold Christensen
- Water, Ice, and Snow - Wilford Weeks

11:45 Summary and Future Activities - S. Rasool

12:30 Adjourn Workshop

1:00 Steering Committee Meeting

2:00 Adjourn

Appendix B

ERSAR

PROGRAM DEFINITION

working group

WORKSHOP REPORT

January 23-25, 1980

Pasadena, California

sponsored by
National Aeronautics and Space Administration
Johnson Space Center
supported by
University of Missouri-Columbia

PREFACE

The ERSAR (Earth Resources Synthetic Aperture Radar) Program Definition Group Workshop held in Pasadena, California, January 23-25, 1980, and the ERSAR Applications Group Workshop held in Houston, Texas, November 7-9, 1979 were two major elements in a series of working sessions to develop a program plan to aid NASA in establishing the value of active microwave sensor data in specific earth resources applications.

This report presents the results of the Program Definition Group Workshop deliberations. The findings represent the judgment of 52 recognized experts in active microwave sensor applications, research and/or technology. The working group was composed of five panels: Geology; Agriculture; Land Cover; Water, Ice, and Snow; and Technology. Each panel reviewed the information needs in each area, determined the required research, and identified specific research tasks that should be undertaken.

The ERSAR Committee was formed to define the role of active microwave sensors in future earth resources programs. The committee is composed of a Steering Committee and various Working Groups. The ten-member Steering Committee includes representatives from NASA Headquarters, Johnson Space Center, Jet Propulsion Laboratory, and the Working Group Chairmen. The Working Groups are composed of recognized experts in the several topic areas of concern, i.e., the Applications Working Group and the Program Definition Working Group include users, researchers, and system specialists knowledgeable in remote sensing data applications and/or active microwave data acquisition and analysis techniques. S.I. Rasool, NASA Headquarters, is General Chairman of the ERSAR Committee; John E. Estes is General Co-Chairman. Anthony Lewis is Chairman of the Applications Working Group. Keith Carver is Chairman of the Program Definition Working Group. M. Jay Harnage, Jr., Johnson Space Center, is ERSAR Committee Coordinator responsible for conducting the working session with support from the University of Missouri-Columbia.

The ERSAR Committee. sponsored by the Johnson Space Center, continues a series of related activities initiated by JSC in 1974. These included the Active Microwave Workshop (1974), Active Microwave Study Group (1975), Active Microwave Users Workshop (1976), Microwave Remote Sensing Symposium/Workshop (1977), and the Shuttle Active Microwave Facility Review (1978).

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LIST OF ACRONYMS AND ABBREVIATIONS

AIDJEX	-	Arctic Ice Dynamics Joint Experiment
ASAR	-	Advanced Synthetic Aperture Radar
cm	-	centimeter
dB	-	Decibel
ERIM	-	Environmental Research Institute of Michigan
ERSAR	-	Earth Resources Synthetic Aperture Radar
ERTS	-	Earth Resources Technology Satellite
FM-CW	-	Frequency Modulation-Continuous Wave
GEOS	-	Geostationary Earth Orbiting Satellite
GHz	-	Gigahertz
GSFC	-	Goddard Space Flight Center
HH	-	Horizontal Transmit-Horizontal Receive
HV	-	Horizontal Transmit-Vertical Receive
ICEX SAWG	-	Ice & Climate Experiment Science & Applications Working Group
IR	-	Infrared
JPL	-	Jet Propulsion Laboratory
JSC	-	Johnson Space Center
km	-	kilometer
KU	-	University of Kansas
LaRC	-	Langley Research Center
m	-	meters
MAS	-	Multispectral Active Microwave System
MHz	-	Megahertz
MSS	-	Multispectral Scanner
NASA	-	National Aeronautics and Space Administration
NOAA	-	National Oceanic and Atmospheric Administration
NSTL	-	National Space Technology Laboratory
RMS	-	Root Mean Square
RPA	-	Resources Planning Act
SAR	-	Synthetic Aperture Radar
SAW/CCD	-	Surface Acoustic Wave/Charge Couple Devices
SIR (SIR-A)	-	Spaceborne Imaging Radar
TAMU	-	Texas A&M University
TM	-	Thematic Mapper
UHF	-	Ultra High Frequency
USGS	-	United States Geological Survey
UTM	-	Universal Transverse Mercator
VIR	-	Visible/Infrared
VV	-	Vertical Transmit-Vertical Receive
λ	-	Wavelength
WMO	-	World Meteorological Organization
C-band	-	Frequency band designation for 4GHz to 8GHz
K-band	-	Frequency band designation for 10.9GHz to 36 GHz
L-band	-	Frequency band designation for 390MHz to 1.55GHz
P-band	-	Frequency band designation for 225MHz to 390MHz
S-band	-	Frequency band designation for 1.55GHz to 5.2GHz
X-band	-	Frequency band designation for 5.2GHz to 10.9GHz

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ERSAR COMMITTEE

The ERSAR (Earth Resources Synthetic Aperture Radar) Committee is a long-term activity initiated by NASA to guide the development of applications which can benefit from active microwave sensor measurements. The overall objective is to establish the validity of active microwave sensor data for accomplishing earth resources applications when used independently or in conjunction with other types of data. The immediate objective is to develop and implement a detailed program plan to guide the research and development efforts in this field.

The ERSAR Committee consists of a Steering Committee and various working groups. The first phase of the Committee's effort involves two working groups: Applications and Program Definition. The ERSAR Committee structure is shown in Figure 1. The Program Definition Working Group participants are shown in Table 1.

WORKSHOP OBJECTIVES

The Applications Working Group addressed two basic questions: (1) What significant earth resources applications can be better addressed if active microwave sensor data were available to supplement existing or proposed data sources, and (2) Why or in what way do active microwave sensor data provide the desired additional information?

The Program Definition Working Group addressed two related questions: (1) How can the applications potential of active microwave imaging sensors best be achieved, and (2) What research tasks should be undertaken to demonstrate and/or validate the measurement capabilities of these sensors? The Working Group was organized into five panels: Geology; Agriculture; Land Cover; Water, Ice, and Snow; and Technology.

Specifically, the Program Definition Group Workshop undertook three tasks: (1) Identify significant gaps in current understanding that should be filled by a well-developed, coordinated research program; (2) Specify the objectives, justification, and prioritization of the research needs; and (3) Make specific recommendations for research tasks designed to satisfy the stated research needs.

This workshop was structured to provide the participants with a summary of the results of the Applications Group Workshop and the status of existing ground-based, aircraft, and spacecraft sensor systems available to support a coordinated research program. The agenda for the Program Definition Group Workshop is appended to this report.

SUMMARY

The objective of the ERSAR Applications Workshop, November 7-9, 1979, was to identify those applications of remotely sensed data that could be better addressed by adding active microwave data to the existing or anticipated data sources. This was accomplished by identifying the proven capabilities of imaging radar sensors and comparing them to the information needs in each of four discipline areas: geology; agriculture; land cover; and water, ice, and snow. This led to an identification of specific research needs. These were listed in the Applications Working Group Report as:

Geology

1. Establish the dependence of radar backscatter on surface roughness and dielectric properties of natural bare and vegetated terrains with special emphasis on optimum wavelength, polarizations, and incident angle for effective measurements.
2. Establish the utility of stereoscopic radar images as aids to geologic interpretation and measurement of vertical relief.
3. Determine the value of repetitive (seasonal) synoptic coverage for geologic applications.
4. Document the potential of orbital image data for environmental monitoring, e.g., oil seeps and spills.

Agriculture

1. Establish the sensitivity of radar backscatter to complex vegetation canopies with special attention to the following crops: corn, sorghum, soybeans, wheat, cotton, sunflowers, and rice; and the following radar parameters: wavelength, polarization, resolution, and incident angle.
2. Establish the value of radar image data as an additional spectral channel to Landsat for improved crop discrimination in a variety of environments.
3. Establish the effect on radar backscatter of soil moisture variations in a variety of environments.
4. Define the required radar image characteristics for effective vegetation-related measurements, with special attention to resolution, calibration accuracy, registration, speckle effects, and dynamic range.
5. Document the potential of radar sensor measurements of timber species, timber volume, and tree vigor as affected by disease and insect infestation.
6. Determine the capability of radar sensing as an aid to determining rangeland productivity and trends.

Land Cover

1. Document the potential of radar image data used independently and/or in conjunction with visible/infrared image data for improving urban area boundary delineation and urban land cover classification accuracy in both manual and automatic mapping and thematic classification. Include an analysis of radar parameters such as resolution, azimuthal look direction, wavelength, polarization, and incident angle.
2. Establish the value of radar/Landsat composite data for improved land cover/land resources mapping with emphasis on multifrequency, multipolarization radar data.

Water, Ice, and Snow

1. Document the capabilities of radar sensors to accurately measure the types, velocities, strains, and strain rates of floating ice, with special emphasis on the marginal ice zone of the Arctic ice pack.
2. Establish the sensitivity of radar backscatter to snowpack characteristics, especially wetness, and to underlying surface conditions. Include analyses of the effect of wavelengths, polarization, and incident angle.
3. Determine the capability of radar sensor data to assist in the development of hydrologic models at varying levels of spatial resolution with special emphasis on the measurement of soil wetness.

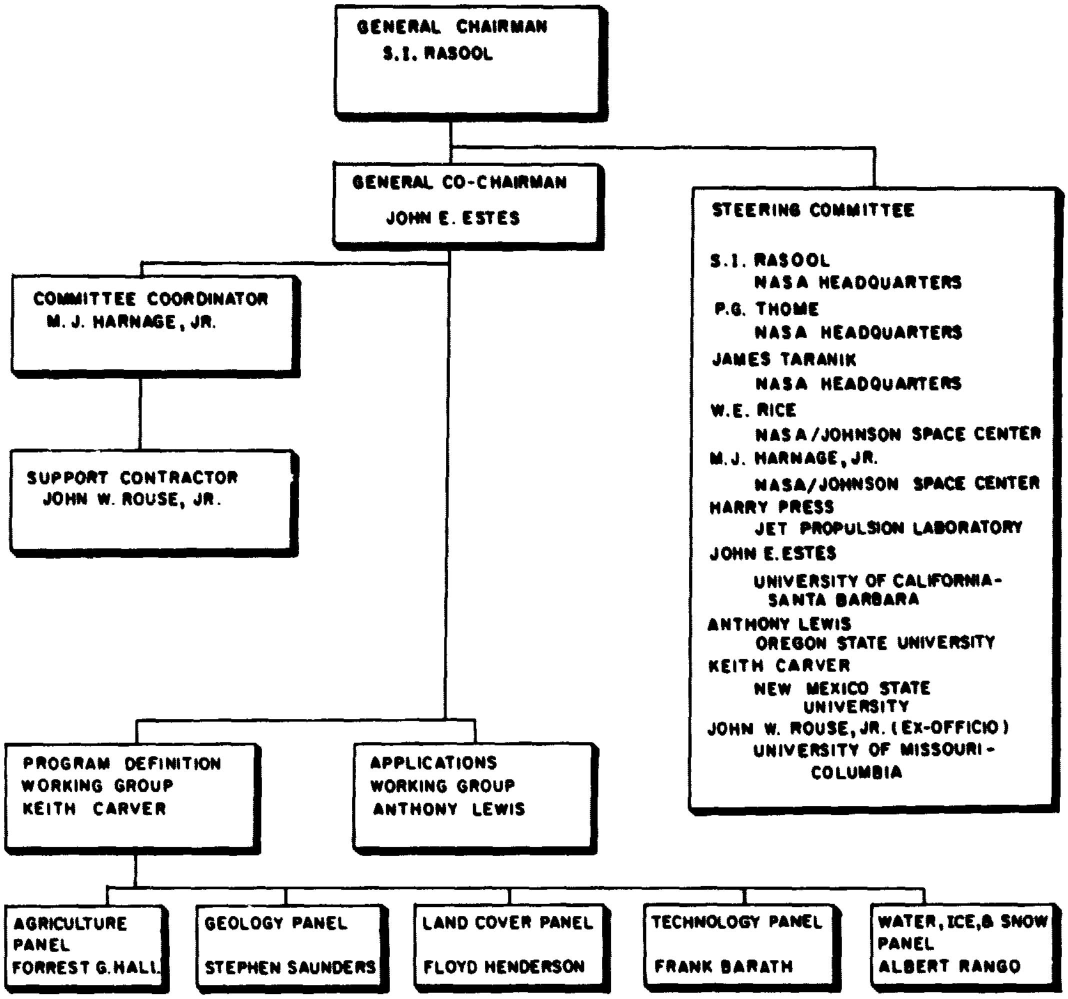
The primary objectives of the ERSAR Program Definition Workshop were to review and confirm these research needs; formulate a research program to satisfy these research needs; and define the technology issues which must be addressed to support the recommended research program.

This Working Group recognized that the understanding of the measurement capabilities of radar sensors was markedly different for different applications. For example, whereas there exists an enormous background of information on the use of radar image data for geologic mapping, there has been virtually no research done in the area of rangeland mapping. The quantity and quality of information available in other application areas is highly variable. This situation required the Group to formulate research tasks which varied from exploratory, e.g., forest mapping, to verification testing, e.g., sea ice mapping.

In the design of each research task, the Group attempted to build on the existing base of empirical and/or theoretical knowledge. However, it is clear, as was stated by the Applications Working Group, that in general, the quantitative understanding of the information content in active microwave sensor data is lacking. This is especially evident when attempting to justify specific operating wavelengths, polarizations, and incident angles. This is due to the fact that very little research in this topic area has been sponsored during the last decade.

The research program recommended by the Program Definition Working Group includes concise statements of

FIGURE 1. ERSAR COMMITTEE STRUCTURE



objectives in each application area, the specific approach to be taken in each task, and an estimate of the level of effort (man-years) required to complete the task.

As noted, each research task is unique to the application of concern and the level of understanding which presently exists in that area. However, the general structure of the overall program includes three basic elements:

1. Modeling of radar signal responses to specific scenes or scene components, using empirical and/or theoretical techniques.

2. Verification of the models for an adequate range of scene (spatial) variables and radar system parameters.

3. Testing of the indicated measurement capabilities of radar sensors in realistic environments, by potential users of these data.

These elements encompass experimental activities which progress from basic measurements, such as provided by ground-based sensors or simple aircraft sensors, e.g. scatterometers, to area-extensive measurements with airborne imaging radar sensors, and finally to spaceborne SAR systems, such as SIR-A. However, the Group expressed some concern about the ability of airborne imaging radar sensors to provide the quality of data required to meet the research needs. The Agriculture Panel in particular, noted that:

"Many characteristics of the aircraft SAR data are not representative of spacecraft data. The relatively large range of incident angles and the relative instability of the aircraft platform introduce distortions into the data sets which would not be present in spacecraft data. This was the experience with visible/infrared aircraft data. With the launch of ERTS (Landsat), a significant breakthrough was possible in the analysis of remote sensing data because the extremely difficult and intractible problems of aircraft scanner data disappeared at spacecraft altitudes. The panel feels that this experience will be repeated, and perhaps be even more difficult with airborne SAR data. While much can be learned with the aircraft platform, these data have ultimate, inherent limitations that can only be overcome through the use of well controlled experimental investigations from spacecraft."

The research program defined in this report is responsive to the needs identified by the Applications Working Group. It is a significantly larger effort in active microwave remote

sensing research than has ever been previously supported by NASA. It will require a major long-term commitment of resources, and most importantly, it will require attentive coordination by NASA and a solid interface with other federal agencies and with the scientific community.

The Technology Panel reviewed the recommended research program relative to the present situation in sensor hardware and technological readiness. It was immediately obvious to the panel that the inventory of sensors and data handling systems in NASA was presently inadequate to carry out the majority of the specified research tasks. This means that the first priority of the overall program must be to upgrade existing sensor systems and expand NASA's capability to acquire and process useful data. The panel defined a program to accomplish the relevant objectives. The panel also identified high priority technology issues that must be addressed early in the program. Foremost among these are calibration techniques.

PANEL REPORTS

The reports of the five panels are essentially reformatted versions of the original material prepared during the three-day workshop in Pasadena, California. This material was reviewed and refined by a team of representatives from each panel during a working session in Houston, Texas, February 9-10, 1980. A copy of the final draft was distributed to all panel members for approval prior to release of this document.

The panel reports are organized to first provide a summary of the research needs. This is followed by a discussion of the approach recommended by the panel to design a research program to provide the desired information. The tasks which should be undertaken in this research program are then described with an indication of the level of effort required. Finally, expected results and/or the improvement in the state-of-knowledge anticipated from the recommended research program are identified.

Table I. PROGRAM DEFINITION WORKING GROUP PARTICIPANTS

AGRICULTURE PANEL

Forrest G. Hall, Chairman
NASA/Johnson Space Center
Andrew Blanchard
Texas A & M University
Richard Gilbert
USDA/Soil Conservation Service
Ray Jackson
USDA/Agriculture Service
Vic Myers
South Dakota State University
Jack Paris
NASA/Johnson Space Center
Leroy Silva
Purdue University
David Simonett
University of California-Santa Barbara
Fawwaz T. Ulaby
University of Kansas

GEOLOGY PANEL

Stephen Saunders, Chairman
Jet Propulsion Laboratory
Walter E. Brown, Jr.
Jet Propulsion Laboratory
Charles Elachi
Jet Propulsion Laboratory
John Ford
Jet Propulsion Laboratory
Paul Harrison
Cities Service Corporation
Phil Jackson
Environmental Research Institute of Michigan
Floyd Sabins
Chevron Oil Field Research Co.
Harry E. Stewart
Jet Propulsion Laboratory

LAND COVER PANEL

Floyd Henderson, Chairman
State University of New York
M. Leonard Bryan
Jet Propulsion Laboratory
Nevin A. Bryant
Jet Propulsion Laboratory
Jerrold Christenson
Environmental Systems Research Institute
John Jensen
University of Georgia
Chih-Tseng Wu
NASA/National Space Technology Laboratory

TECHNOLOGY PANEL

Frank T. Barath, Chairman
Jet Propulsion Laboratory
Richard Fenner
NASA/Johnson Space Center
Lee Graham
Goodyear Aerospace Corporation
Dan Held
Jet Propulsion Laboratory
Randall Jean
Texas A & M University
Rolando Jordan
Jet Propulsion Laboratory
Kumar Krishen
NASA/Johnson Space Center
Stanley Marder
Environmental Research Institute of Michigan
William McFarland
University of Missouri-Columbia
James Shiue
NASA/Goddard Space Flight Center
Len Tyler
Stanford University
Charlie Wu
Jet Propulsion Laboratory

WATER, ICE, AND SNOW PANEL

Albert Rango, Chairman
NASA/Goddard Space Flight Center
Paul Bock
University of Connecticut
Frank Carsey
NASA/Goddard Space Flight Center
Ted Engman
United States Department of Agriculture
Donald Moore
South Dakota State University
Richard Newton
Texas A & M University
Wilford Weeks
U.S. Army CRREL

GEOLOGY

RESEARCH NEEDS

The ERSAR Applications Working Group examined the current state-of-knowledge in the application of SAR to research in geology. The conclusions of that panel were:

1. The Geological user community currently understands how to use SAR in a qualitative way to supplement geologic mapping. The current need for this purpose is a uniform SAR data base similar to that of Landsat.
2. Research is most needed to relate radar system variables to properties of the land surface to allow quantitative geologic assessment of surface cover and topography.
3. Effort needs to be expended in the area of education and training, and data archiving and distribution.

The Geology Panel of the Program Definition Working Group reviewed these recommendations and defined the programmatic requirements appropriate to address the research needs in this area.

There is an existing body of literature that supports the assertion that geologists are currently using SAR data to supplement other data types (Bryan, M. L., 1979, Bibliography of Geologic Studies Using Imaging Radar, JPL Publication 79-53, JPL, Pasadena, CA). Some gaps exist in the understanding of the uniqueness of SAR data for particular applications, the limitations of SAR data, and in the comparison of information derived from SAR data with information available from other sources such as Landsat, other remote sensors, and field mapping. These gaps can be filled by the research tasks outlined in this section.

The major need at present for exploration is a uniform SAR data base, with broad coverage, which could be immediately used in conjunction with other data sets and applied to geologic studies by industry, NASA, and the university community. For this purpose, the major contribution of SAR is that it provides additional surface topographic information and an indication of variations in surface roughness and electrical properties which can be related to geologic materials. Research is needed primarily to better define functional requirements of a useful synoptic data set; to further document the potential of SAR as an important supplementary data set; and to improve interpretation techniques, in particular to minimize confusion factors.

In order to be in a position to establish an effective program to further analyze the potential of SAR images for Earth Resources research, NASA must assess the availability and state of documentation of radar image data from aircraft (Goodyear, Motorola, Westinghouse, ERIM, JSC, JPL) and spacecraft (Seasat and SIR-A). Investigators should be able to obtain a listing of images of their field area, information about the data (date, system, depression angle, etc.), and how to obtain these data.

The goal should be to reach the point where the decision can be made as to the necessity and detailed nature of a program to acquire a global or synoptic regional SAR data set. At this time, the optimum system parameters cannot be specified in detail. However, the functional requirements for a global data base can be stated. These are:

1. Extensive land coverage, including synoptic coverage of a wide variety of geomorphic provinces.
2. The viewing geometry should be uniform for a major part of the coverage. The viewing angle effects in SAR data are terrain dependent. These effects need further study.
3. Spatial resolution equivalent to the Thematic Mapper, both spatial and grey-level discrimination. The definition of SAR image quality in terms of these parameters needs further study.
4. Digital format consistent with Landsat, i.e., registration of ground-range image.
5. Depression angle small enough to avoid layover. The optimum angles cannot be specified at this time.
6. Geometric fidelity for cartographic and radargrammetric purposes. These requirements require further study and definition.
7. Swath width at least 50 km.
8. SAR wavelength appropriate to application. Optimum wavelengths are yet to be determined.

Several of the above items are addressed in the recommended research program. The panel agrees that a synoptic data set at X-band would be useful, but there is no demonstrated basis at present, beyond considerable experience with high quality X-band image data, to assert that any frequency is optimum for geology applications. Much of the L-band imagery (Seasat, JPL) is not comparable in quality with X-band data, e.g., Goodyear or ERIM X-band images. To resolve this uncertainty will require further research.

Additionally, no recommendation can be made at this time as to whether a future mission to acquire a global data set requires a free-flyer or can be accomplished with several Shuttle flights. The desired data set should be obtained in the most expedient mission configuration.

An additional concern which should be given high priority is training in SAR image interpretation. Geologists trained in conventional air photo interpretation can extract most of the information in a SAR image, but they can extract more information with training that addresses the differences between SAR images and conventional air photos. In addition, effort must be given to the problem of archiving and distribution of existing SAR data, and a plan should be developed for handling future data.

In summary, this panel agrees with the research thrust recommendations of the ERSAR Applications Working Group, and suggests that the three priorities are coordinate items, specifically:

1. If a systematic, uniform SAR data base were available, it could be immediately used in conjunction with other commonly used sensor data. However, further documentation of applications needs to be done to demonstrate the utility of SAR in comparative studies using other data.
2. There is a need to continue quantitative work on electromagnetic/surface interactions over a range of geologically interesting targets.
3. There is a need to increase training, and data archiving and distribution.

Geology research will require data from existing and planned support efforts, including SIR-A data, Seasat data, ground-based (truck and helicopter) measurements, and more data from existing aircraft systems, along with improvement of their data quality.

The programmatic goal is to understand the potential of radar for geologic applications. The geology community will continue to use SAR data in ways that are currently understood, and to improve interpretive techniques in specific ways such as in development of computer methods for comparing other data types with SAR. The principal objective is to produce better geologic maps as a basis for a wide range of investigations and decisions. It must be recognized that SAR will be only one of many data types used.

APPROACH

Geologic information is extracted from radar images by either of two methods: empirical correlation between form and texture in a radar image and a hypothetical geological model (A in Figure 2); or by deriving landscape information from the radar image (B), followed by geologic inference from features in the landscape (C).

The analysis of lineaments is an example of the first method. Lineaments in a radar image are successfully used to corroborate and extend a structural interpretation, but little attention is given to definition of the landscape elements comprising the lineament. The empirical correlation (A) has proven extremely successful for geologists. For many applications, the method can be considered operational. It is likely that many of the future

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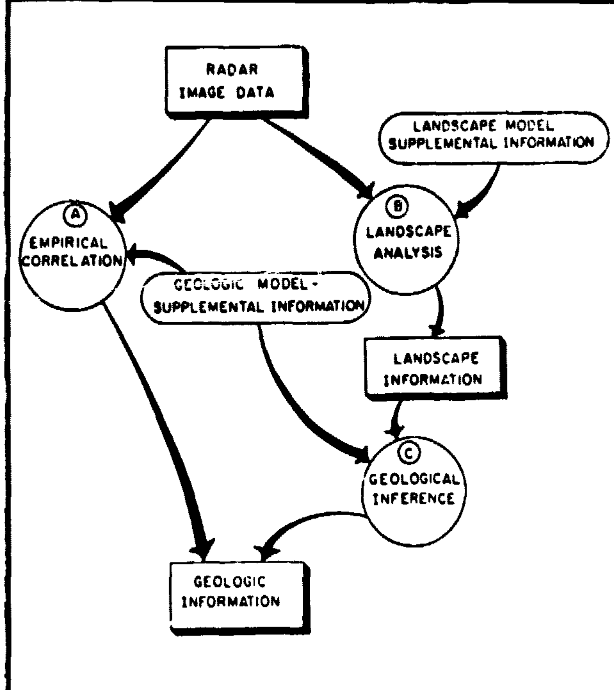

Figure 2. Schematic of Alternative Methods For Deriving Geologic Information from Radar Data

applications in radar geology will come through further development of this method. Therefore, Task I of the radar geology program is to place good quality radar data in the hands of users who are working on geologic problems that are likely to be amenable to radar methods.

The weakness in the first method (A) is that the interpretation skips development of an understanding of the precise landscape elements detectable in the radar data. Without identifying these landscape elements, there has been little incentive to develop an understanding of the radar backscatter that permits specification of optimum radar system parameters. Furthermore, without concern for the characteristics of the radar backscatter, the costs of acquiring radar data having high geometric and radiometric fidelity has not been justifiable. High quality data are required for information extraction techniques employing multiple data sets. Consequently, the geological analysis of radar data does not yet incorporate the advanced processing techniques now common in the analysis of Landsat data.

The alternative to the empirical correlation is the landscape analysis (B) followed by geological inference (C). This requires that the backscatter characteristics of elements in a radar scene be understood. A product of this attention to backscatter characteristics is the possibility of specifying desired radar performance, machine merging, and processing of multiple data sets. Task 2 of this plan is to develop adequate backscatter models for various terrain types, to develop landscape analysis techniques based upon processing multiple data sets, and to specify optimum radar system parameters.

The type and morphology of surface rock and soil, the distribution of soil moisture, and the distribution and vigor of plant species are each influenced by underlying geology. Therefore, the characteristics of these surfaces are potential sources of geologic information. To the intent that these characteristics are derivable from radar data, the radar data become a potential source of geologic information. This plan entails developing scattering models for three distinct terrains: bare rock and soil, grassland, and forest.

The second method of extracting geologic information from radar data yields landscape information from which geologic inference (C) is possible. Many of these geological inferences are demonstrably sound. For example, topography is a proven indicator of geologic structure. However, some landscape information believed derivable from radar data is not as readily relatable to underlying geology. For example, soil moisture anomalies sometimes appear to be a product of the geology, and some shifts in the species distribution in forested terrain correlate with underlying soil and rock types. The geologists have not had access to regional, detailed maps of soil moisture, nor to maps of forest species distributions, and, consequently, interpretive techniques based upon such data do not exist. Radar methods will provide new types of landscape information for geologic interpretation. Task 3 of this plan is to develop interpretive methods for these new information sets.

TASKS

The objective of this program is to gain a clear understanding of the potential of radar data for geologic applications. The specific objectives of the three tasks recommended are:

1. To document empirical correlations between radiometric patterns in radar data and geologic information with the specific objectives of expanding the set of known applications of radar in geology, and developing the user community.
2. To determine interactions of active microwave radiation with topography and surface cover.
3. To develop correlations between topographic and surface cover characteristics detected by radar systems, and geological information.

TASK I: Empirical Correlations

The programmatic approach to be followed includes:

1. Identifying user/investigators who have existing field programs that would benefit from radar data, and who would be willing to provide a test of radar applications to geology.
2. Providing the user/investigators with desired data in standardized formats and accuracies.
3. Having the user document the results of field investigations with radar data.

This will require the following specific actions:

1. Identify and document all available aircraft and spacecraft imagery (including Seasat and SIR-A) and establish a distribution system to appropriately format and disseminate image data.
2. Establish criteria for user group field study data bases and initiate investigations to determine the suitability of existing or planned SIR data for the field area under study.
3. Select user group study areas on a continuing basis with some attention paid to assuring that a wide variety of geologic problems are addressed.

Successful completion of this task will mean that for the first time the researcher will have available all existing SAR data, documented and cataloged. The selected investigators will document geologic applications of SAR images, and provide a base of SAR related field studies to guide the technical approach to Task 3. The results will also guide the selection of landscape features that will be studied under Task 2. A final report consisting of all research papers derived from the studies will be compiled. It is expected that many of the investigators in this phase of the program will conduct investigations under Task 3.

TASK 2: Electromagnetic/Surface Interactions

The objectives of this task are to:

1. Systematically develop an understanding of radar backscatter.
2. Examine the effect of topography on radar backscatter.

3. Combine radar backscatter data with other data derived from Landsat, digital topography, etc., to develop interpretive techniques for separating the effects of topography and surface cover.

4. Specify radar system parameters necessary for optimum discrimination between different surface cover situations, for discrimination of topography and of texture.

The work must encompass different major surface cover situations, e.g., rock and soil (usually less that 30% vegetation), grass and soil (usually greater that 30% vegetation, but lacking canopy), and forested terrain (usually greater than 30% vegetation, but having a canopy).

The understanding of radar backscatter from bare rock and soil, from grasslands, and from forests will be achieved through the development of adequate theoretical models, and through testing and verification of these models in the laboratory and in the field. The functional dependence of radar backscatter upon the physical characteristics of most natural surfaces is sufficiently complex that exact theoretical solutions are not practical. However, empirical correlations without corroborative theory are often ambiguous or even misleading. Both difficulties can be avoided by combining the development and testing of appropriately simplified theoretical models with the validation of these models through field observations. The product of this activity should be practical theoretical radar backscatter models that are specific enough to be useful.

The recommended approach involves two major steps:

1. Establish three science teams to acquire and analyze data. The teams will primarily examine one of the three major terrain types: bare rock and soil, grasslands, and forests. Each team will design a three year program containing the following elements:

   a. Survey existing data and theory pertaining to their terrain of interest.

   b. Describe terrain types to be studied in field.

   c. Define requirements for a system to acquire field data at the test sites.

   d. Acquire data and develop appropriate models.

   e. Design tests of models for adequacy in interpreting multi-parameter radar data derived from airborne or Shuttle radar observations.

   f. Apply models with objective of determining potential of SAR for deriving quantitative landscape information. This might involve direct extraction of information or developing a comprehensive set of solutions for a set of landscapes, i.e., computer model simulations, in order to interpret images of these areas.

   g. Evaluate the combination of radar data and Landsat, topographic, or other data to search for techniques that allow maximum geologic information extraction. For example, using experimental or theoretical models, topographic effects can be separated from ground cover effects.

   h. On the basis of the research program, specify sets of radar system parameters including resolution, wavelength, polarization, depression angle, look direction, and image quality (resolution and grey levels) that are required for specific geologic research applications.

2. Programmatically evaluate the results of the research to arrive at a decision on whether to proceed with a dedicated spaceborne SAR program.

Existing field scatterometers will be required to conduct field experiments to establish the relations among the surface parameters (scattering properties and electrical properties) and radiometric variables (frequency, polarization, incident angle). Truck and aircraft mounted systems are needed to gain access to all terrain types and to examine the spatial variability within single types. Laboratory measurements of electrical properties and scattering properties are needed to check and guide the development of theoretical models. Based on results of field scatterometer experiments, existing airborne SAR imaging systems with frequencies appropriate to the particular experiment will be flown. Calibrated images will be needed. A capability to perform digital image processing is needed to quantitatively compare SAR images with Landsat and to model topographic effects.

Research projects under Task 2 will provide validated scattering models for three characteristic terrains: bare rock and soil, grasslands, and forest. These scattering models will incorporate the effects of both ground cover and topography. Radar system parameters will be identified that provide optimum discrimination among geologically relevant landscape features. Methods will be developed for extracting geologically relevant landscape information from multiple data sets.

This activity will allow the specification of geologically relevant radar data, and the objective extraction of landscape information from these radar data.

TASK 3: Topographic and Surface Cover Characteristics

The objectives of this task are to (1) identify topographic and surface cover characteristics that can be uniquely detected by radar, or by using a combination of radar and other electromagnetic data, for example, soil moisture patterns or vegetation patterns that are related to the underlying geology, to define the uniqueness and ubiquity of these particular correlations, and (2) define the radar system parameters necessary for their detection.

The recommended approach follows these steps:

1. Select a committee of geologists who are representative of the research community and have them identify test sites in different physiographic environments where ground information can be readily acquired.

2. Initiate research using radar technology defined in Task 2, and the test sites defined by Step 1 above.

3. Select an investigation team from the proposed research studies of the test sites.

4. Have the investigation team evaluate significant changes in landscape cover caused by seasonality, and determine the repetitive coverage requirements for each test site.

5. Using the repetitive coverage requirements for each test site, the investigations team should determine the airborne radar and ground data required for analysis of each test site in the light of technology defined by achievements of Task 2.

6. Repetitive airborne radar data and ground data will be acquired simultaneously over the test sites and over other areas having physiographic environments both similar and different than the test sites.

   a. Airborne radar data will be acquired using standardized radar systems, i.e., systems which are calibrated, which use the same polarizations, frequencies, and imaging geometries with respect to the Earth's surface. The characteristics of these systems will be defined by Task 2.

   b. Ground data will be acquired within the test sites defined by the original investigation team using ground instrumentation defined by Task 2.

7. After the airborne radar and ground data are acquired, process and archive data in the standardized formats which preserve the calibration.

8. Announce to the user community the availability of the airborne radar data and ground data, and provide funds for analysis and interpretation of these data.

9. Review applications and research oriented proposals.

10. Select investigators (Note: The investigator community would have been developed through Task 1.)

11. Review the results of the applications research with standardized calibrated radar data.

12. Define the unique applications of radar data for the development of geological information.

13. Evaluate the requirements of the geological community for radar data.

14. Make recommendations for the development of an operational spaceborne radar data collection system if appropriate.

Successful completion of this task will develop an understanding of the types of geological information which can be extracted from analysis of radar data. This will allow the potential of radar data for geologic applications to be assessed in terms of the needs of the user community for such data.

EXPECTED RESULTS

With the completion of these tasks, the set of documented, successful applications of radar in geology will have grown significantly, and the community of geologists familiar with radar data and their use will be commensurably larger. The understanding of radar backscatter from natural terrain will have progressed to the point that optimum radar parameters for various geological studies can be defined, and application demonstrations using aircraft or the SIR facility can be planned. Objective procedures will have been demonstrated for combining radar data with other data sets, and for extracting landscape information from these combined data sets. Various types of radar derived landscape information will have been used to infer geologic information and the quality of these inferences will have been checked, and the potential of radar for geologic applications will be known.

AGRICULTURE

This section describes a five-year program of basic and applied research, development, and applications systems evaluation of remote sensing for agricultural information needs.

The overall goals of the program are to assess the extent to which active microwave data can be used independently or in combination with visible and infrared data, as an integral part of existing or future agricultural information systems, to improve the objectivity, reliability, timeliness, and adequacy of the information required by the agricultural community. This knowledge will provide a base on which to design future agriculture remote sensing applications systems.

The approach is comprised of a balanced program of remote sensing research, development, and testing which addresses agricultural resource management as well as commodity information needs. Information needs in crop land, forest land, rangeland, and soils applications are addressed with essentially parallel research efforts in scene/radiation characterization, large-area efforts in algorithm verification, pattern recognition and analysis (information extraction), and data preprocessing and processing.

INFORMATION NEEDS

The Agriculture Panel of the ERSAR Applications Working Group defined a broad group of information needs within crop lands, forest lands, rangelands, and soils applications. That panel also ranked each information need in terms of its importance; defined the role of visible/infrared data and synthetic aperture radar (SAR) data as primary or complementary; estimated the "frequency of sample" required; estimated the research effort required; and estimated the potential for success. That panel developed a table (Table 5, p. 12, ERSAR Applications Workshop Report) displaying these parameters.

The current Agriculture Panel of the ERSAR Program Definition Working Group reviewed the prioritization and estimates made by the Applications Working Group, revised them, and produced the information shown in Table 2. Each application element was prioritized based on the relative importance of radar with respect to visible/infrared sensors to satisfy the information needs; the estimated potential for successfully satisfying the information need by adding radar as a data source; the status of radar technology, i.e., the state-of-knowledge relative to satisfying the information need; and the economic importance of the application.

These evaluations resulted in the list of agriculture application information needs shown in Table 3. Such a ranking selects application needs which are of highest economic importance and have the highest payoff potential for the use of radar. After considering these relative rankings, the panel selected a further categorization of these needs into Category I needs and Category II needs. The agricultural radar program definition herein is designed specifically to address only the Category I needs, however, the research program defined will have impact on Category II needs.

For the highest priority applications area, crop productivity estimation, a paradigm is shown in Figure 3.

Beginning with planting at the start of the season, acreage information is the most important parameter for an estimate of crop production at harvest. Acreage remains primary until a month or so prior to harvest when yield becomes primary as the crop nears the completion of its process and yield becomes much more predictable. Early in the season, radar data can be a key input to crop identification and area estimation, especially when obscuring cloud cover prevents visible/infrared data acquisition. At this time, radar data estimates of pre-growing season soil moisture are also crucial in yield forecasts, assessment of planting conditions, and initiation of the crop development stage models. Crop development stage estimates are key to both the crop identification activity and yield estimation. As the season progresses, radar information could continue to improve the accuracy of crop identification by filling gaps left by cloud cover and by adding information discrimination power when visible/infrared data are available. In very cloudy environments radar will perforce be the primary agricultural sensor.

Radar data may also provide key parameters to yield production. Radar data tend to be sensitive to both canopy water content, which is a measure of plant vigor and condition, as well as to soil moisture, a potential key input to yield.

The information categories: crop area, crop yield, crop condition, and crop stage development, are all vital inputs to an information category of major economic importance, i.e., crop production. Radar data appear to have great potential for increasing the timeliness and accuracy with which all these information needs can be satisfied.

Augmentation of the Landsat-type technology by SAR is considered attractive from several aspects.

1. SAR data have greatly decreased sensitivity to atmospheric effects including clouds, which obstruct visible/infrared sensors.
2. SAR data have high spatial resolution potential.
3. Microwave interaction with crop canopies and soils may be unique and/or complementary to visible/infrared interactions.

The other major attributes of SAR image data of particular value to agricultural applications are:

1. Timeliness (weather independent system).
2. Penetration capabilities.
3. Response to electrical and geometric properties of the target.
4. Potential for higher data sampling frequency.

The penetration of cloud cover enables imaging at most times, in contrast to the cloud-restricted imaging of Landsat. In monitoring of growing vegetation, several temporal and spatial limitations are imposed by Landsat imagery. Clouds can often prevent sequential imaging of a specific area, and can also restrict the spatial extent displayed in Landsat imaging. These restrictions are mostly eliminated with imaging radar. The continually changing conditions of all vegetation require timely observation to properly plan at both national and local levels. Severe economic consequences can occur because of improper planning based on incomplete data. In addition, the cloud-penetrating radar can be used to obtain images of regions which are perpetually cloud-covered, such as the Amazon

Table 2. Active Microwave Sensor Potential and General Status for Agricultural Applications

Application Task	Role VIR	Role SAR	Sensor Revisit Interval	Report Freq.	Research Effort Required	Success Potential	Status	Priority	Comments
IMPROVED CROP PRODUCTION PREDICTION IN TEMPERATE REGIONS									
Temperate									
A. Acreage	P/C*	C/P*	10 days	monthly	H	M	SE	1	*VIR prime in clear weather--radar in cloudy conditions
B. Yield Information	P/C	P/C	10 days	monthly	VH	M	PS	1	VIR responds to canopy geometry, chlorophyll content and, to a lesser degree, water content. SAR responds to canopy geometry and water content. The combination can provide better clarification accuracy than either alone.
C. Crop Condition	P/C	P/C	10 days	monthly	H	M/H	PS/PT	1	
D. Crop Stage	P/C	P/C	10 days	monthly	H	M/H	PS/PT	1	
IMPROVED CROP PRODUCTION IN TROPICAL REGIONS									
A. Acreage	C	P	10 days	monthly	VH	M/H	PT	1	
B. Yield Information	C	P	10 days	monthly	VH	M/H	PT	1	The cloud cover problem in tropical environments places radar in a primary indispensable role.
C. Crop Condition	C	P	10 days	monthly	VH	M/H	PT	1	
D. Stage	C	P	10 days	monthly	VH	M/H	PT	1	
SOIL RESOURCE									
A. Soil Maps	P	C	3 months	10 years	H	L	IE	1	Backscatter sensitivity to soil type is over shadowed by sensitivity to other science parameters.
B. Crop Growth Potential			Seasonal						
1. Salinity	C	P	3-[illegible] samples*	annual	H	M/H	PS/PT	2	*See soil moisture comments
2. Soil	P	C	3 months	5 years	H	L/M	IE	3	
3. Soil Moisture	C	P	3 days	monthly	H	M	SE*	1	*Strong evidence that radar is sensitive to soil moisture large scale test needed to demonstrate improvements in yield prediction.
C. Soil and Water Conservation Practices	P/C	P/C	3 months/ Seasonal	3 years	M	M	SE	3	Really a land use activity.
FOREST RESOURCE ASSESSMENT IN TEMPERATE REGIONS									
A. Extent	P/C	P/C	3 months/ seasonal	5 years	M	M	SE	1	See Note 1
B. Condition	P/C	P/C	3 months/ seasonal	5 years	H	L/M	UT/PT	1	See Note 2
C. Forest Resource Map	P/C	P/C	3 months/ seasonal	5 years	M	M	UT/PT	2	See Note 3
D. Changes in Forest Resource Base	P/C	P/C	3 months/ seasonal	annual	M/H	M/H	SE	1	See Note 4
E. Insects & Disease	P/C	C/P	bi-weekly	as necessary	H	L/M	IE	1	See Note 5
F. Fuel Condition	P/C	P/C	3 days	as necessary	H	M	IE	2	See Note 6
G. Wetlands & Related Wildlife Habitat	P	C	3 months/ seasonal	2 years	L	M/H	SE/PS	1	See Note 7

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Table 2. (continued)

Application Task	Role VIR	Role SAR	Sensor Revisit Interval	Report Freq.	Research Effort Required	Success Potential	Status	Priority	Comments
TROPICAL FOREST ASSESSMENT									
A. Mapping of Areal Extent	C	P	3 months/ seasonal	5 years	M	M	SE/PS	1	See Note 8
B. Major Type ID	C	P	3 months/ seasonal	5 years	M	H	PS	1	See Note 9
C. Deforestation Rates	C	P	3 months/ seasonal	2 years	H	H	PS/PT	1	Map once ever 2 years See Note 10
RANGELANDS									
A. Vegetation Mapping	P/C	P/C	3 months/ seasonal	5 years*	H	M/H	PS/PT	1	*Map only once in 5 years
B. Productivity Assessment Conditions & Trend	P/C	P/C	3 years/ seasonal	2-4 weeks	H	M	PT	1	2 weeks early early season; monthly thereafter
C. Monitoring Intensive Grazing Systems	P	C		5 years	H	H		3	
D. Monitoring Changes in Wildlife Habitat	P	C	3 months/ seasonal	annual	H	H	IE	3	

NOTE: H = High, M = Medium, L = Low; P = Primary, C = Complementary, 1 = Highest Priority

IE = insufficient evidence
SE = strong evidence of capability
PC = proven capability
PS = potential suggested by experiment
PT = potential suggested by theory
UT = under test

Note 1 The separation of forest from near-forest land is assigned a rating of SE--strong evidence of capability. [illegible] is confined to areas of modest relief. For mountainous areas, the intrinsive radar properties of slope compr[illegible] and lay-over for slopes facing the radar and shadowing on back-slopes may prove intractable. Research will be req[illegible] to determine if these effects may in fact be compensated for through use of ascending and descending orbit images. In areas of gentle slopes, evidence of radar images of forest/new-forest boundaries, e.g., the U.S., the Amazon Basin, New Guinea, and Panama, clearly shows the boundaries are distinguishable from shadowing/bright illumination where boundaries are orthogonal to the beam. Where it is parallel, the problem is more difficult, but ascending and descending space images should be used to eliminate this problem. For all areas seasonal differences in the forest/background will require four looks at approriate times of the year.

Note 2 This potential is rated low to moderate because of two uncertainties: (1) whether the phenomenon will be detectable, even if of wide area extent, and of large contiguous blocks, and (2) whether patchy and isolated small areas of low condition can be separated from healthy forest in the presence of speckle, or after removal of the latter in preprocessing.

Note 3 This potential is rated moderate because mapping of forest types depends not only on structure but also species composition. While radar is sensitive to differences in structure, it is not necessarily sensitive to species composition. Topographic effects will also confuse discrimination.

Note 4 This potential is rated high because once forest type mapping is done with any sensor, change detection and discrimination is intrinsically a less demanding problem than initial type discrimination. Mountainous areas may prove unsuitable for detection of change, though ascending and descending orbit images may be adequate to answer the problem. No formal research on the topic has been carried out, though inspection of radar imagery of different data in areas of low relief suggest the capability may be met.

Note 5 This potential is rated low to moderate because of two uncertainties: (1) whether the phenomenon will be detectable, even if of wide extent and in large contiguous blocks; and (2) whether patchy, isolated small areas or single trees subject to infestation and disease can be separated from healthy forest in the presence of speckle, or after removal of the latter by preprocessing. In any case multi-date, multi-frequency, multipolarization radar almost assuredly will be required.

Note 6 This potential is guessed as moderate. No research has been carried out and may need to await actual satellite data. Single date images are unlikely to be useful. Experiments with multi-date, multi-sensor, multi-frequency/polarization radar may be required. [illegible] truck-based experiments may give preliminary indications of the possibilities. Genuine experiments would be very costly with aircraft radar.

Note 7 This potential is rated moderate to high because wetland areas tend to bring into juxtaposition widely differing vegetation water/soil environments to which radar is sensitive. Once mapping of communities has been carried out by ground and remote sensing, the monitoring of change is intrinsically a less demanding problem than initial identification. Experiments with seasonal images, preferably of more than one wavelength and polarization will be needed.

Note 8 This potential is estimated as moderate. Where tree cutting takes place and good-sized bites are taken from the forest, the potential is high. Where scattered, small areas are involved, of irregular shape, the potential may be low to moderate. The overall potential is measured as moderate because there is no single answer.

Note 9 This potential is rated as high. Single data, single frequency, and single polarization radar has been used in Brazil to discriminate between forest types. The result was only of moderate success. The ranking of high is assigned in anticipation of the increment of information very likely with multi-date, multi-frequency, and multipolarization imagery.

Note 10 This potential is rated high. Much clearing of forest land in the tropics is for conversion to cultivated, or rangeland and is a one-time event. Boundaries between forest and new forest tend to be clearly distinguishable on radar imagery even of single date, frequency, and polarization. Future improved capability coupled with radar's all-weather sensing will assure its having a prime role from space for this purpose.

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TABLE 3. AGRICULTURE APPLICATION INFORMATION NEEDS

Priority	Category	Information need
1	I	Crop Production Information (area, yield/condition/soil moisture, growth development)
2	I	Forest Extent Information (extent and change in extent)
3	I	Rangeland Production Information (vegetation mapping and production assessment)
4	I	Soils Information (saline soils detection and mapping)
5	II	Forest condition, forest resource mapping, rangelands grazing monitoring
6	II	Forest insect & disease detection
7	II	Forest Fuel condition
8	II	Wildlife habitat change monitoring
9	II	Soil erosion

Basin, South and East Asia, and other wet tropical areas.

Forest land information needs are driven by the requirement to determine forest extent and condition. The Resources Planning Act (RPA) of 1974 mandates the U.S. Forest Service to determine the extent and condition of the forest and rangeland resources every 10 years. The potential of active microwave image data for forest resource assessment is significant. SAR sensors have certain capabilities that offer unique advantages for forestry applications as compared to other data collection systems. These include:

1. The apparent ability of SAR data to provide differences in return that are related to stand density and structure offers the potential to more effectively differentiate among various species and forest cover types than may be possible with MSS data, even from the Thematic Mapper (TM). The combination of SAR and TM data would appear to offer the greatest promise for mapping forest cover types and defining density and size classes.

2. The potential of SAR data to map and monitor deforestation of tropical forest lands is of particular importance from two standpoints: SAR can obtain data in areas of persistent cloud cover; and differences in stand structure such as a fairly recent clear-cut overgrown with brush and a full size jungle forest canopy, should be apparent of SAR, whereas such differences may not be particularly evident in the optical portion of the spectrum. Monitoring the extent and rate of deforestation of tropical forests should be given high priority because of these potentially unique capabilities of SAR sensors, and the importance and concern for this application.

Rangeland needs are similar in nature to the forestry requirements. The location (wilderness) and extent (large areas) make the ability to supply this need difficult.

The rangeland parameters that should be investigated relative to their assessment by SAR sensors are:

1. Total canopy cover.
2. Bare ground and soil moisture content.
3. Moisture content of vegetation.
4. Some phenological expressions as they relate to either plant moisture content or radar texture based on subtle changes in species or vegetation surface geometry.
5. Vegetation structure or geometry, including height, to determine the potential of SAR to use changes in vegetation structure and height within the stand to infer species composition, or at least the presence or absence of certain important species within the stand.
6. Detailed landform depiction may lead to better evaluation of landform-soil-vegetation correlations.

RESEARCH NEEDS

To define the research needs for establishing the capability of radar data in agricultural applications, it is extremely important to do so in the context of the overall remote sensing problem. This problem can be generally described as follows: The application involves an object scene, containing a number of classes of interest (defined by some taxonomy such as crop type, rock type, etc.). Each class of interest is further described by attributes of interest such as condition attributes, canopy moisture content, maturity, canopy biomass, stage of maturity and so on.

The user of a remote sensing data set is interested in identifying these object scene classes and attributes within classes. Unfortunately there is not always, and in most cases is not, a stable one-to-one functional relationship between spectral classes in the remote sensing image space or spectral space and user information classes and class attributes. Such relationships may exist in principle but uncontrollable factors such as atmospheric interference, sensor calibration changes, within field and between field variations in class condition, e.g., crop maturity stage, and weather events, e.g., heavy rains, hail or snow, can drastically modify these relationships.

Thus, the remote sensing analyst cannot always infer uniquely the nature of objects in the object scene from the remote sensing data. Instead (s)he may have to resort to image analysis and pattern recognition techniques. The use of such techniques relies on both a knowledge of the functional relationships known to exist in principle between the object scene and the remote sensing data, as well as statistical techniques, such as clustering and maximum likelihood classification, to deal with uncertainties introduced by random variables such as scanner noise, crop planting date, and soil background variation.

The Panel recommends a research program consisting of three major categories of research:

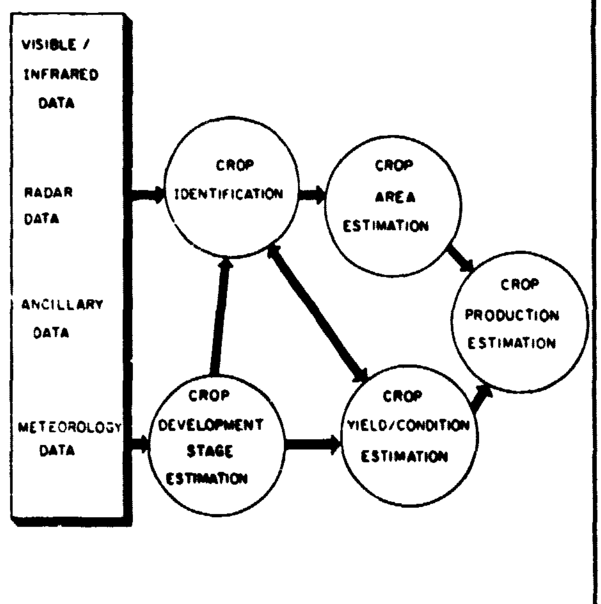


Figure 3. Paradigm for Crop Production Estimation

1. Theoretical, laboratory, and field research to develop and verify models relating object scene classes and attributes to the characteristics in the visible/infrared and SAR multi-date data sets;

2. Research in extended areas using candidate algorithms, image analysis and pattern recognition investigation,

a. to establish relationships over extended areas between the characterisitics of the visible/infrared and SAR multi-date data sets and the object scene classes and attributes,

b. to evaluate and modify existing visible/infrared pattern recognition algorithms to analyze composite visible/infrared and SAR data; and

3. Research in large areas to investigate the data preprocessing and processing requirements to correct for sensor and atmospheric effects in the SAR data, to register the SAR data to the VIR data, or in any other way, to render VIR and SAR data sets mutually compatible for image analysis and pattern recognition techniques.

These three general research activities are crucial to developing SAR applications for all of the application needs addressed in this program. The technical issues that must be addressed in the research tasks are:

1. Determine the nature of SAR data response to complex vegetation systems in terms of canopy and soil geometry and electrical parameters.

a. Develop theoretical, predictive models for these interactions based on multi-frequency, multi-angle, multi-polarization, multi-temporal and multi-date empirical data from laboratory, truck, helicopter, aircraft and/or spacecraft data.

b. Perform an inversion of such models to produce candidate algorithms for SAR and visible/infrared data processing in terms of user information units.

c. Perform an inversion of such models to improve labeling schemes for pattern recognition techniques using multi-date, multi-band SAR and visible/infrared registered data sets for user information units determination.

2. Determine revisit intervals or specific visit times (related to growth stage) needed to optimize crop identification and areal measurement.

3. Determine if direct indicators of crop condition and yield are present in SAR data.

4. Determine if direct indicators of crop growth stage condition are present in SAR data.

5. Determine if root zone soil moisture estimation needed for crop yield and crop growth stage estimation can be improved by use of SAR data.

6. Determine if cross-polarized SAR data is useful in agricultural information needs.

7. Determine the effects of topography on information extraction from SAR data over large areas.

8. Determine the effects of inter and intra-field variations on information extraction from SAR data over large areas.

9. Determine the best hierarchial or stratification approach needed for information extraction from SAR data over large areas.

10. Determine the degree to which SAR data improves agricultural information estimation as compared to visible/infrared data.

11. Determine the best method to reduce spatial noise (speckle) due to coherent effects in SAR data while preserving spatial resolution.

12. Determine if atmospheric effects on SAR data are significant, and, if significant, develop atmospheric correction algorithms.

13. Determine the information content of the textural information in SAR data.

14. Verify the contention that C-band data are optimum for SAR sensing of soil moisture.

15. Determine if the effects of crop canopy on the soil moisture estimation by SAR data can be handled from an algorithmic point of view.

16. Determine how well the soil moisture, crop yield, and crop growth stage estimation procedures work in different areas in extended agricultural sites having different crop types and other vegetal cover, different planting and growth time sequences, and different soil types.

17. Determine what configuration a spacecraft SAR should have for agriculture area, condition, yield, and stage growth applications.

APPROACH

The general objective of the ERSAR Agricultural research program defined in this plan is to conduct basic and applied research into the relationships between synthetic aperture radar (SAR) observations over agricultural areas (crop land, forest land, rangeland, and soils) and desired user defined information units in agriculture; to develop information extraction techniques; and to evaluate candidate applications systems with and without visible/infrared sensor system observations over the same agricultural areas so that the basis for the planning for a future earth resources synthetic aperture radar spacecraft system can be established.

A five-year research program is given in each of these areas which consists of parallel and interactive tasks in scene/radiation characterization, extended area use of algorithms, image analysis and pattern recognition, and data processing research areas. It is recommended that controlled experiments be conducted over agricultural test sites which have adequate ground observations. In cases where ongoing, instrumented sites exist, the recommended research program should make use of them. In AgRISTARS, for example, several heavily instrumented sites already exist for the crop experiments. Adding SAR to these experiments would take advantage of a large body of ongoing work.

It will also be extremely important to acquire aircraft data over these tests sites to begin to understand the nature of SAR data over the extended areas. SAR and visible/infrared image products should be investigated to establish relationships between these multi-spectral data sets and the object scene classes and attributes. Feature selection studies should be conducted to see in what part of spectral and/or temporal feature space the majority of the information is contained. Image products utilizing these features should be generated and used to develop preliminary image interpretation procedures.

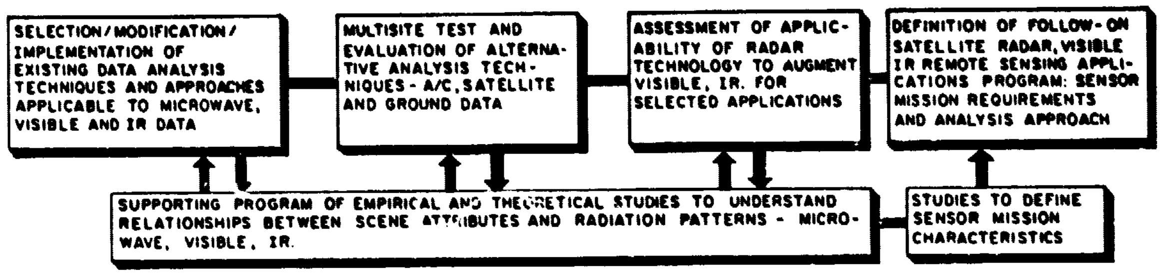
Many characteristics of the aircraft SAR data are not representative of spacecraft data. The relatively large range of incident angles and the relative instability of the aircraft platform introduce distortions into the data sets which would not be present in spacecraft data. This was the experience with visible/infrared aircraft data. With the launch of ERTS (Landsat), a significant breakthrough was possible in the analysis of remote sensing data because the extremely difficult and intractible problems of aircraft scanner data disappeared at spacecraft altitudes. The panel feels that this experience will be repeated, and perhaps be even more difficult with airborne SAR data. While much can be learned with the aircraft platform, these data have ultimate, inherent limitations that can only be overcome through the use of well controlled experimental investigations from spacecraft.

If the limitations from aircraft data are to be minimized, the third part of the research activities, data preprocessing and processing must also be vigorously pursued. The use of aircraft data to understand a spacecraft application requires that the aircraft data duplicate as nearly as possible radiometric and statistical characteristics of the spacecraft data.

It is extremely important that the scene radiation characterization studies, the extended algorithm studies, and the image analysis and pattern recognition studies be conducted in a closely interacting and parallel fashion. Figure 4 illustrates this relationship.

The final objective of the study should be directed at not only ascertaining the value of radar for the various space

FIGURE 4. TECHNICAL APPROACH
TO RADAR APPLICATIONS PROGRAM



applications, but also to define the fundamental characteristics of the sensor and the satellite that will best fulfill these application information needs.

The research program defined in this plan is a unified approach involving:

1. Intensive basic research into scene/radiation characterization using frequently acquired (1-10 day revisit intervals) truck or helicopter field data over small fields, and corresponding theoretical investigations.

2. Extended area applied research studies using aircraft systems to allow investigation and development of extended area analysis interpretation algorithms, and use of pattern recognition and image analysis techniques.

3. Completion of preprocessing and processing systems (hardware and software) to allow reasonably efficient throughput of data, and to optimize the quality of SAR data being used in the applied research efforts.

The proposed research program consists of four levels of experimentation: laboratory and theoretical investigations, truck and helicopter-based experiments, aircraft investigations, and spacecraft experiments.

These four activities have been placed in two categories of activities:

1. Scene/radiation characterization in small areas and laboratories
   a. laboratory investigations
   b. theoretical investigations
   c. truck and helicopter-based experiments over small fields
2. Analysis techniques research and evaluation in large areas (5x10km)
   a. aircraft-based experiments
   b. spacecraft-based experiment opportunities
   c. algorithm development for extended area applications
   d. pattern recognition and image and analysis techniques investigations
   e. preprocessing, software development, and data base management

Although, many sensor parameters can be examined in a truck-based field measurements program, the truck-system can only visit a few fields a day. To obtain a synoptic view of many fields, aircraft or spacecraft data bases must be used.

TASKS

Scene/Radiation Characterization Research

The general objective of the scene/radiation characterization research is to determine the relationship between remotely sensed features of a crop, forest, range, or soil scene and the scene parameters that affect the remote sensing observables.

The basic approaches (as illustrated in Figure 5) to this objective are as follows:

1. Extensive empirical measurements are made by wide range multi-spectral (VIR/radar) sensor system over selected crop, forest, range, and soil small area sites using multiple configurations (angles of viewing, polarization, orientations) on multiple dates and at multiple times of day (multi-temporal character).

2. Theoretical models are developed to predict the scattering and emissive properties of crops, forest, range, and soil, as well as atmospheric absorption and scattering properties.

3. Theoretical models are evaluated against empirical models and are improved as necessary to produce a tractable, pragmatic model for remote sensing image and non-image data interpretation.

4. Theoretical models are used to predict (simulate) the spatial distribution of remote sensing observables over large areas taking into account the distribution of controlling parameters in the large area.

5. Theoretical models are inverted to produce a set of interpretation algorithms that use remotely sensed inputs and output values of scene parameters.

6. Theoretical models are used to produce labeling aids for use in pattern recognition and image analysis approaches to large area information extraction.

7. Inversion algorithms and labeling-aids are evaluated by use of simulated large area image data and by use of measured large area image data in blind sites.

Scene/radiation characterization begins with the understanding of how various physical phenomena affect spectral observables. Where feasible, theoretical studies will be conducted to model these effects. Experiments will be conducted under controlled/man-made conditions to measure the variations in microwave observables due to various physical parameters. Both active and passive microwave sensors should be used in these studies. Truck-based systems will be used to develop basic relationships and verify mathematical models. Aircraft sensors will be used in the applied research program to verify/modify the mathematical models derived from the truck-based and theoretical studies. Where possible, parallel investigations from spacecraft sensors will be conducted to further understand and verify the field and aircraft results. Experimental procedures will be developed for the spacecraft studies. The verification from spacecraft data will be conducted using data gathered over extended geographical areas similar to Landsat studies.

The factors affecting the microwave observables are definable either on the basis of theoretical models or the experimental data published in the literature. For the soil moisture and crop investigations, the parameters identified in past studies are:

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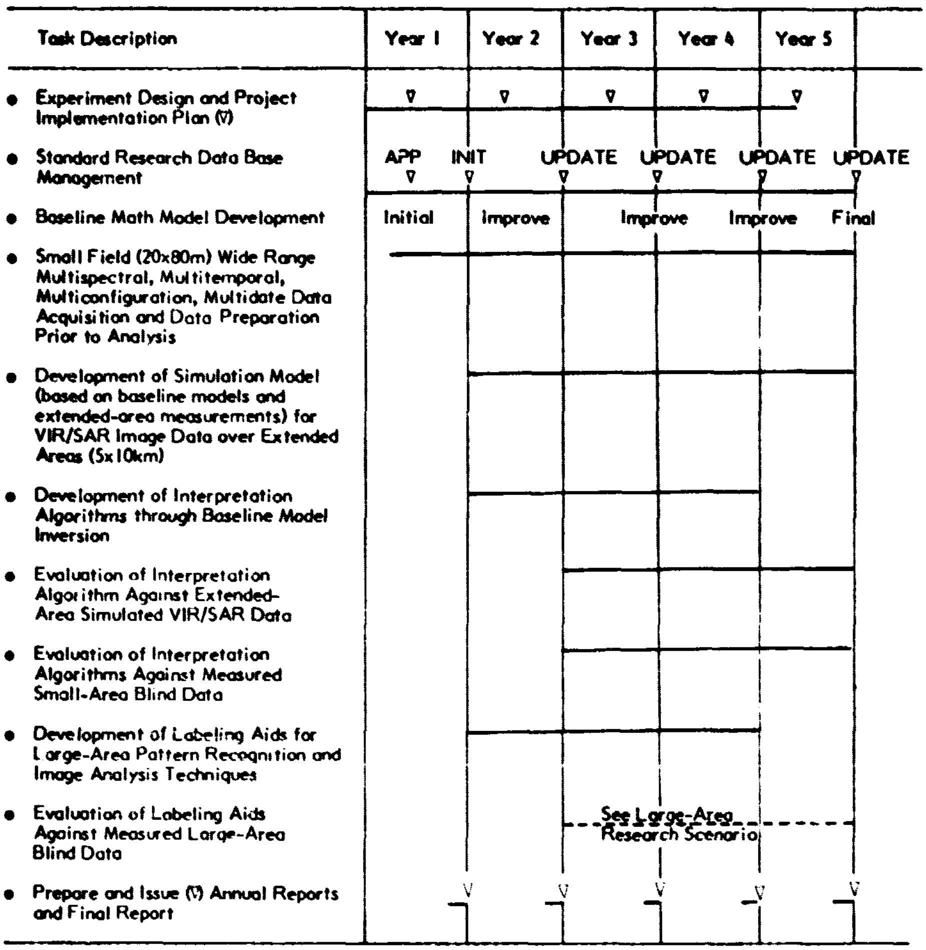
FIGURE 5. GENERAL SCENE/RADIATION CHARACTERIZATION RESEARCH TASKS SCENARIO



1. Soil type and texture,
2. Soil moisture distribution,
3. Soil temperature distribution,
4. Surface slope and roughness,
5. Vegetation cover (type, maturity, condition health and distribution),
6. Surface atmospheric conditions (temperature, pressure, humidity, winds, rainfall), and
7. Time and season (diurnal variation, sun angle).

For the forest inventory investigations, the physical parameters affecting microwave signals include:

1. Tree type,
2. Tree density,
3. Tree condition/health and maturity,
4. Soil type and moisture,
5. Vegetation cover, excluding the trees,
6. Atmospheric conditions, and
7. Season.

The effects of all these physical parameters should be studied in order to estimate the accuracy/repeatability with which a certain parameter can be estimated. This requires either theoretical modeling or experimental data acquisition and analysis under various conditions.

TASK 1: Crop Area Research

The objective of this task is to determine the capability of combined active microwave sensor data and visible/infrared data to identify major crops (wheat, barley, other small grains, corn, sorghum, cotton, and rice), and to measure their areal cover in a crop estimation system. This determination should be based upon accurate and well-calibrated field measurements on small plots with appropriate truck, tower, or helicopter-borne multispectral sensor systems. Theoretical models should be developed, tested, and evaluated using the empirical field measurements to quantify the understanding of the relationship between scene characteristics and sensor measurements so that candidate algorithms can be developed to interpret remotely sensed data in terms of desired crop and soil information.

The plan involves the following activities:

1. Develop baseline mathematical models to predict the radar backscattering of crop canopies and soil as functions of sensor configuration, frequency, and related crop canopy geometric and material properties.

2. Acquire wide-range multispectral, multi-temporal, multi-date data from truck or helicopter-based platforms

over wheat, barley, corn, soybeans, cotton, and rice small fields (20x80m), complete initial processing, and prepare the data for analysis and inclusion in the standard research data base. Observations should be made from emergence through harvest at about 10-day revisit intervals.

3. Use baseline models to produce simulation models for VIR/SAR image data over large area having wheat, barley, corn, soybeans, cotton, and rice.

4. Develop algorithms to use remote sensing observations to classify wheat, barley, corn, soybeans, cotton, and rice (without use of pattern recognition or image analysis techniques) for use in large area analyses. Algorithms will be developed by inversion of baseline mathematical models.

5. Develop labeling aids for large area pattern recognition and image analysis techniques for classification and area estimation of wheat, barley, corn, soybeans, cotton, and rice.

6. Evaluate interpretation algorithms for crops by using large area simulation data.

7. Evaluate interpretation algorithms for crops by using small area blind site data.

8. Perform final overall evaluations to include specification of the optimum configuration of a wide range multispectral (VIR/SAR) spacecraft system for crop area.

This task will require 6-8 man-years per year level of effort over a 5-year period, plus the cost of data acquisition.

TASK 2: Crop Condition/Yield Research

The objective of this task is to determine the capability of active microwave sensor data to assist in estimating crop yield with several crop type categories (wheat, barley, corn, sorghum, cotton, rice), and assessing crop condition and crop microenvironment. This objective will be pursued with the cooperation of parallel efforts in AgRISTARS, the Yield Project, and the Soil Moisture Project. This task focuses on the problem of relating radar observables to crop condition and yield through direct sensing of canopy changes that might indicate that plant stress is occuring; and by indirect monitoring of yield by monitoring the microenvironment of the crop to assess yield potential at planting, early growth conditions, and environmental effects on final yield at harvest, through physiological crop growth modeling.

It is anticipated that this effort will require very short (1-10 day) revisit intervals which, without spacecraft data, cannot be easily assimilated except by intensive truck-based experiments on small field plots.

This task involves the following activities:

1. Develop baseline mathematical models to predict backscattering by agricultural crops and fields as functions of crop condition and soil conditions.

2. Develop mathematical models to predict yield given microenvironmental conditions and direct monitored crop moisture stress condition.

3. Develop baseline models for root zone soil moisture estimation and effects on yield.

4. Acquire small area (20x80m) wide range multispectral, multitemporal, multiconfiguration, multidate data, processor data, and prepare data for analysis with emphasis on wheat, barley, corn, soybeans, sorghum, and cotton for estimation of root zone soil moisture.

5. Develop algorithms to predict yield in crop areas using wide range multispectral data.

6. Develop labeling aids for yield estimation and classification in large areas by pattern recognition and image analysis.

This task will require a 4-6 man-year per year level of effort over a 5 year period.

TASK 3: Crop Stage of Development

The objective of this task is to document the feasibility of using radar data to detect the change in, or the existence of, crop growth stages in major crops. Radar backscatter is affected by the large scale morphology of the plant canopy; hence, certain crop growth stages may present unique signatures to radar.

This task involves the following activities:

1. Acquire radar data over crops during different growth stages.

2. Develop baseline mathematical models for crop morphological changes as detected by radar.

3. Develop labeling aids for crop growth stage by pattern recognition.

4. Evaluate results of testing of crop growth stage algorithms in large areas.

This task will require a 3-4 man-year per year level of effort over a 5-year period plus data acquisition costs.

TASK 4: Forest Mapping

The objective of the scene radiation characterization studies in forestry will be to develop the basic knowledge required to define and to evaluate the feasibility of using spaceborne SAR data in conjunction with VIR data to map forest extent and forest change. The interaction process which governs the backscatter of radar signal from targets which have the geometry and electrical characteristics of forest cover are not well understood; the background of work done in forestry applications is extremely limited. Some airborne data exist which indicates some capability of radar in forestry applications. However, the data are qualitative, and consistent analysis and use of the possible information content from these targets has yet to be accomplished.

A great deal of basic research will be required to determine the information content in radar data backscattered from forested terrain. Basically, the program is defined to determine the characteristics of forest systems which could possibly be measured by radar systems. What forest parameters (tree height, density, vegetation water content, and tree geometry) influence radar backscatter, and how can the radar response from forest system physical parameters be described? This research effort will consist of modeling efforts to describe the interaction of the radar signal with targets that have the physical and electrical parameters of forest stands. These models will be verified and refined using ground-based and/or airborne scatterometer measurements over specific well described test sites. Response to forest parameters with respect to frequency, incident angle and polarization will be determined empirically; supported by theoretical models defining the interaction process.

This task involves the following activities:

1. Refine or complete development of general model describing radar signal/scene interaction phenomena using, where appropriate, results of truck-based and/or airborne experiments.

2. Initiate development of specific simulation models as needed to support or explain specific phenomena measured from ground-based or airborne platforms.

3. Acquire and analyze truck-based or airborne scatterometry data for use in more completely describing the fundamental relationships between radar and forested scenes.

4. Predict effects of slope, understory vegetation, soil drainage, and other conditions as needed for development of comprehensive models for radar/forest interactions.

This task requires a 2-3 man-year per year level of effort plus data acquisition costs over a 5-year period of time.

TASK 5: Rangeland applications

The research effort in range vegetation mapping and range production assessment using radar is virtually nonexistent. Very little is known about the microwave response of range vegetation systems. Range production is associated with condition (green biomass) and type of vegetation. Vegetation classification will provide an essential element in range productivity assessment. The research effort will

consist of identifying the microwave response to range vegetation species along with the development of mathematical models which can predict the behavior of radar backscatter to these species. The lack of an adequate data base requires that the first several years of research effort be devoted to acquiring that data base and beginning the processes of understanding the interaction phenomena. Truck or airborne acquired data will be used to provide the data base required to develop and refine the models describing the radar-scene interaction process.

This task involves the following activities:

1. Review previous work related to radar measurements of rangeland, data manipulation, and data analysis.
2. Begin acquisition and analysis of ground-based or airborne data to provide an indication of applications feasibility, and to indicate directions for subsequent research.
3. Initiate development of general theoretical model(s) describing radar-range scene interactions.
4. Model the sensors and calibration procedures used in small area radar-range studies to predict accuracy, drift, response to spurious signals, and precision.
5. Using ground-based scatterometry, determine penetration of grass cover as a function of grass type, height, density, and moisture.

This task involves a 2-3 man-year per year level of effort plus data acquisitions costs over a 5-year period of time.

TASK 6: Soil Salinity Determination

The objective of this task is to develop models using radar data to differentiate moisture stress and saline soil stress in irrigated fields.

The approach includes the following activities:

1. Select and instrument test fields that represent soil saline extremes.
2. Acquire radar data over fields throughout growing season.
3. Develop models using radar data to verify that soil salinity and soil moisture can be determined.
4. Refine models to measure various levels of salinity. Quantify the results such that various levels of stress caused by soil salinity can be measured.

This task will require a 2-3 man-year per year effort over a 5-year period, plus the cost of data acquisition.

Analysis Techniques Research and Evaluation in Large Areas

The general objective of the analysis techniques research and evaluation in large areas is to evaluate candidate algorithms (developed under the scene/radiation characterization research) and to develop and to test pattern recognition techniques against training and blind test site aircraft or spacecraft data acquired over large areas (5x10km) so that the information content of SAR and SAR/VIR data can be compared to that of visible/infrared (VIR) data above for agricultural information needs.

The basic approaches (as illustrated in Figure 6) to this objective are as follows:

1. Previously acquired large area data (e.g., Colby, Kansas, and Seasat SAR data in 1978) are processed and used in the evaluation and in planning other large area data acquisitions.
2. Extensive wide range multispectral (VIR/radar) sensor measurements are made each of the first four years over crop, forest, and range test sites to provide data for candidate algorithm evaluation and pattern recognition technique development and evaluation.
3. A preprocessing and processing system is developed and made operational in the first three years to enable correction of SAR data as necessary for sensor and atmospheric effects, to merge SAR and VIR image data sets, to merge multi-date data sets; to register data sets to base maps, to apply and to evaluate candidate algorithms; and to evaluate pattern recognition and image analysis techniques to the large area data acquired in 2 above.
4. Candidate algorithms are evaluated against blind site data starting in the third fiscal year.
5. Candidate labeling aids are evaluated against blind site data starting in the third fiscal year.
6. Pattern recognition techniques are developed for SAR/VIR data sets starting in the second fiscal year and are evaluated against blind site data starting in the third fiscal year.

The tasks identified under the scene/radiation characterization area concentrate on obtaining better descriptions of the interaction of radar signals with terrain elements, i.e., crop canopy, moist soils, etc. Those tasks should expand the fundamental understanding of radar remote sensing and provide additional quantitative evidence of the capabilities and potential of this sensing technique.

The tasks identified in the analysis techniques research and evaluation area concentrate on developing methods of extracting and using the information in radar image data. The approach used in these tasks features extended area scenes, e.g., AgRISTARS Super Sites, rather than the small plots featured in the previous tasks. It also features the use of image data, rather than scatterometer measurements. Consequently, image processing and image analysis techniques become a significant factor in this research.

TASK 1: Crop Area Research

The objectives of this task are to determine the sensitivity of radar data to plant/canopy characteristics; determine the effects of background noise on the ability of radar to discriminate between crop types; determine the optimum sensor parameters; determine the best way to mix radar and MSS data; and determine the added classification performance of radar and MSS data compared to MSS data alone.

The approach requires the acquisition of radar image data and visible/infrared image data over large areas to:

1. Study radar image data to determine sensitivity to growth state, total biomass, plant morphology, background effects (soil type, precipitation, etc.), indicent angle, frequency of coverage, and polarization.
2. Study radar and MSS data to determine tradeoff between hierarchial versus multivariate classification.
3. Study radar and MSS data to determine added classification performance of radar and MSS pixel resolution of registered data and sensitivity of registration error.
4. Study radar and MSS data over large areas to determine added classification performance of radar and MSS data over MSS data alone. Determine best temporal sampling strategy and sensitivity to background effects (soil type, soil moisture, management practices).
5. Study radar and MSS data over large areas to determine added labeling performances with MSS and radar data over MSS data alone, and the potential for signature extension.
6. Determine the accuracy of data interpretation algorithms developed in small area research when used in large areas.
7. Determine the natural spatial variability of crop type signature over a large area due to differing planting dates, environments, farming practices, and harvest dates.
8. Determine the usefulness of spatial information, e.g., texture, in radar imagery by image analysis.
9. Provide aircraft-based testing of applications information extraction systems proposed for spacecraft-based SAR.
10. Complete the operational data preprocessing and processing system to handle increased frequency of aircraft SAR and scatterometer data acquisitions.
11. Use and evaluate interpretation algorithms (see Scene/Radiation Characterization Section).
12. Use and evaluate labeling aids with pattern recognition and image analysis system.

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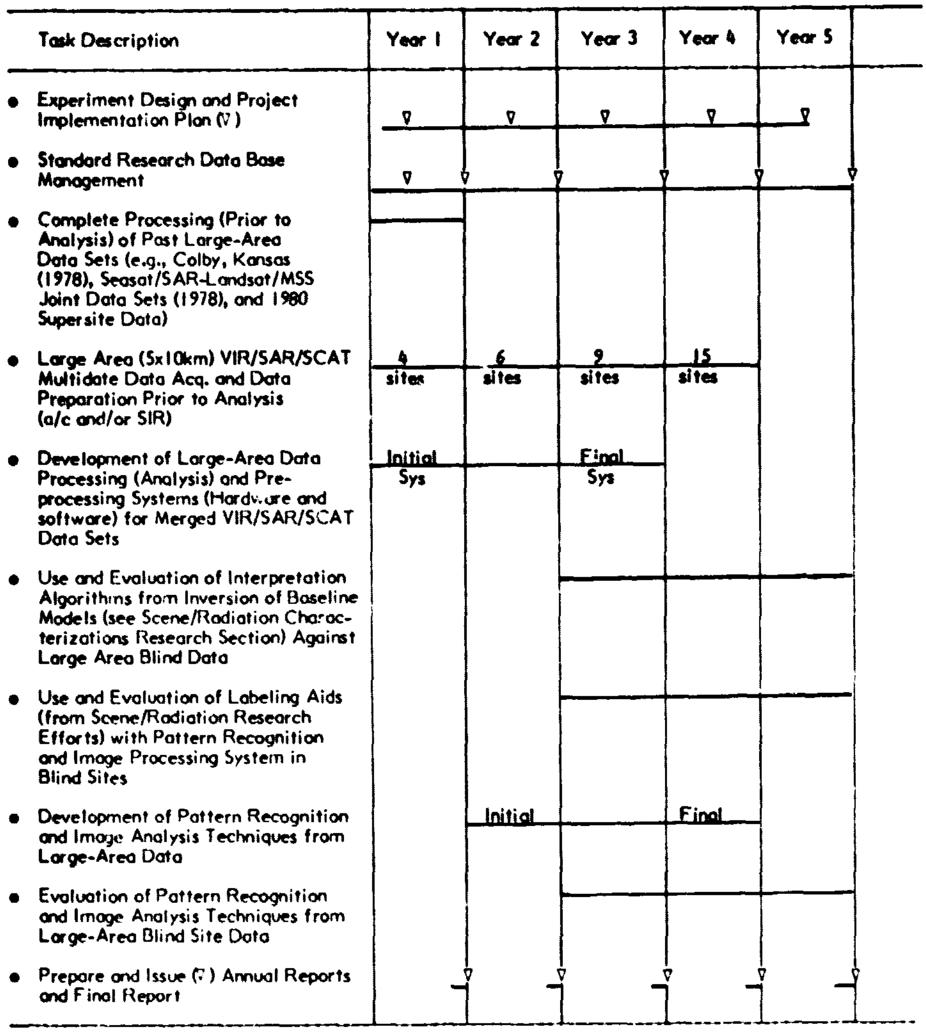
FIGURE 6. GENERAL LARGE AREA RESEARCH TASKS SCENARIO



This task will require a 10-12 man-year per year level of effort over a 5-year period, plus cost of data acquisition.

TASK 2: Crop Condition/Yield Research

The objectives of this task are to determine the sensitivity of radar data to plant/canopy characteristics related to crop stress and yield; determine the ability of radar and MSS data to predict crop stress and yield; and determine the improved performance that can be achieved by adding radar and MSS data to weather data.

Radar image data will be acquired over large area test sites to:

1. Determine sensitivity to biomass, soil moisture, plant/canopy moisture, crop disease, and background and atmospheric effects.

2. Correlate stress indicators and radar data; correlate yield and radar data; and determine added benefits of including radar data with weather data to predict yield, and best temporal sampling strategy.

3. Perform multiple correlations between stress indicators and radar, MSS, and weather data. Determine benefits of including radar and MSS data with weather data to predict yield.

4. Determine performance of yield predictor using MSS, radar, and weather data. Determine benefits of adding radar and MSS data to weather data for crop stress/yield prediction. Determine sensitivity of yield and crop stress prediction to background noise (soil type, crop management factors, etc.).

This task will require a 8-10 man-year per year level of effort over 5 years, plus the cost of data acquisition.

TASK 3: Crop Stage of Development Research

The objective of this task is to determine plant/canopy factors which can be measured by radar sensors; and determine the benefits of adding radar to MSS data, plus weather data, for predicting crop stages.

The activity required includes:

1. Determine sensitivity of radar data to crop stage development; effects of different incident angles; background and atmospheric effects; frequency of coverage required; and relationship between plant/canopy moisture and crop stage.

2. Determine the benefits of including radar data with weather data to predict crop stage, and develop an appropriate temporal sampling strategy.

3. Determine the benefits of including MSS data with radar and weather data to predict crop stage and minimize atmospheric and background effects.

4. Determine size of prediction area (one pixel or a group of pixels), extendability of growth stage models over different areas, and sensitivity of models to background noise (soil type, crop management factors, etc.).

This task will require a 4-6 man-year effort over 5 years.

TASK 4: Forest Mapping

The objective is to determine the feasibility of using SAR data to map major forest land types (extent and change).

1. Acquire airborne SAR data over one forested site in conjunction with crop data acquisition to provide a baseline data set for use in developing data correction and processing procedures. Site must have large areas each of deciduous and evergreen trees.

2. Process and analyze X-band SAR/VIR data obtained over Grand County, Colorado, during June 1979.

3. Develop initial techniques for large area SAR/VIR data handling and analysis including distortion (geometric and radiometric, which are due to radar foreshortening), radar/VIR merging, registration, data evaluation, and classification algorithms.

4. Acquire multifrequency, multipolarization airborne SAR/VIR data multitemporally over one or more forests exhibiting several tree species and maturities.

5. Preprocess and process the data for classification and condition assessment for several combinations of radar/VIR instrument bands and configurations, including radar only, radar/VIR, and VIR only.

6. Develop/improve techniques for minimizing and evaluating geometric and radiometric distortion due to foreshortening. Provide recommendations for forest area exclusion based upon slope magnitude, if necessary, where slope effects would cause excessive error in classification and condition assessment.

7. Provide preliminary forestry applications assessment and recommendations for optimal spaceborne SAR instrument configurations, operational criteria (including data acquisition dates), and data manipulation techniques.

8. Develop algorithms for use in forest scene change detection, forest stand condition (including stress due to insect and disease damage), and total forest stand biomass for fuel assessment pruposes.

This task requires a 6-8 man-year per year level of effort over a 5-year period, plus data acquisition costs.

TASK 5: Rangeland Mapping

The objective is to determine the feasibility of using SAR data to map rangeland vegetation.

This task involves the following activities:

1. Process and analyze X-band SAR/VIR data obtained over Weld County, Colorado, grassland site during June 1979.

2. Acquire multiparameter airborne SAR/VIR data multitemporally over one or more rangeland areas exhibiting relatively large homogeneous conditions for vegetation type, condition, density, and maturity.

3. Initiate development of algorithms for rangeland total biomass and condition determination. Refine/develop techniques for data registration and merging.

4. Perform data processing and analysis to provide accuracy and reliability criteria for several combinations of SAR and VIR bands and configurations for the SAR only, SAR/VIR, and VIR only cases.

This task requires a 3-4 man-year per year level of effort over a 5-year period, plus data acquisition costs.

TASK 6: Saline Soils

The objective is to determine the ability of SAR for detecting and mapping areas undergoing damage by saline seeps.

This task involves the following activities:

1. Test and refine models to measure various levels of salinity.

2. Develop and test approaches for detection of encroachment of saline areas for estimation of decline of productivity.

This task involves a 2-3 man-year per year level of effort, plus data acquisition costs.

TASK 7: Systems Analysis

The objective of this task is to perform an overall systems analysis from an applications viewpoint in which comparative assessment of forecasted performance is made between a number of system scenarios involving combinations of Landsat/SAR satellites. Issues of system redundancy, back up, and operational stability in light of launch schedule capability will be incorporated.

This activity will:

1. Determine incremental Landsat acquisition frequencies and temporal nearness to critical biostage transitions obtained in going from n to n + 1 Landsats, using world-wide cloud/haze distribution data.

2. Model and forecast total system (satellites and ground data system) costs of a mix of n Landsats and m SAR satellites using two scenarios: radar and MSS on same vehicle, and radar and MSS on different vehicles.

3. Model and forecast potential economic and performance improvement in crop production estimation as a function of SAR multi-mode complexity.

4. Construct and rank multiple scenarios in which performance and economic benefit (via crop production forecasts) are associated with modeled system cost to give comparative ranking of the mix of Landsat and SAR satellites.

5. Develop system deployment plan for two or three scenarios which are forecasted as the most beneficial mix of Landsats and SAR satellites for significant performance increase in crop production estimation.

This task will require a 4-6 man-year per year level of effort over a 5-year period.

Image Processing Research

For radar imagery to achieve its maximum potential either in support of optical region sensors or by itself, preprocessing procedures must be applied to the images. These will be required for any or all of the following reasons:

1. To eliminate or reduce incident angle and look angle dependencies in the data, including that arising from topographic effects, as well as the sensor attitude.

2. To eliminate any residual atmospheric effects.

3. To eliminate or reduce radar speckle (fading) effects.

4. To geometrically correct/rectify radar imagery to register with standard projection.

5. To eliminate high-frequency, topographic-induced image distortions so that both registration with other sensors and rectification for final incorporation in a data base may be achieved.

6. To re-sample the imagery after application of the above procedures to a standard resolution/projection, compatible with uniform Federal data bases.

These data preprocessing steps will be essential, and they must be carried out in a central processing facility. Only the Federal government has the resources and the rationale for assuming such a role; such costs cannot be borne by individuals or modest institutions.

All these preprocessing steps require research. All are of at least moderate technical difficulty. Some, such as removal of topographic effects, are major undertakings which require special purpose hardware/software development.

Research on these topics will need to establish:

1. Look-angle and incident angle effects.
2. Atmospheric effects.
3. Speckle effects.
4. Geometric registration and rectification.
5. Pre-sampling effects.

TASK 1: Rectification/Registration

The objectives of this task are to develop techniques for correcting image distortions caused by residual aircraft/spacecraft parameters, particularly yaw; develop image formats (ground range, short range, stereo, etc.) for agriculture/range and forest scenes; and develop registration and resampling techniques/algorithms which will allow spatial registration of multi-beam, multifrequency, multipolarization, multidate SAR data and MSS data, including terrain relief, for computer analysis/pattern recognition.

The approach includes the following activities:

1. Quantify requirements.
2. Develop techniques for image rectification and test these with aircraft data.
3. Identify data format problems/needs by evaluating imagery from selected instruments, crop, range, and forest land areas.
4. Develop algorithms for planimetric image representation/format for areas identified by the applications investigators.
5. Initiate image registration studies and identify alternate approaches, such as precorrelation and after-date correlation.
6. Develop and test computer algorithms to register images by the same sensor on one aircraft at different angles, polarizations, and wavelengths, and study multi-SAR registration.
7. Develop computer algorithms to register image data from various sensors (aircraft/spacecraft).
8. Test algorithms with SIR-A and aircraft data.

This task will require a 4-6 man-year per year effort over 5 years.

TASK 2: Spatial Noise Reduction

The objectives of this task are to determine the extent of averaging needed for acceptable speckle for each agriculture application, and implement data preprocessing algorithms based on empirical/analytic models for each application within agriculture. The algorithms are to be developed through field experiments and/or analytical modeling.

The approach involves the following activities:

1. Develop computer programs/algorithms to generate images with selectable spatial and multi-look, multi-pass data averaging capability.
2. Process selected imagery from crop, range, and forest land scenes.
3. Evaluate image quality for each application area and determine parameters suitable for application data processing.
4. Implement data preprocessing algorithms identified by application investigators, for example, normalized backscatter algorithm.
5. Evaluate suitability of processed data for application investigations.
6. Develop appropriate algorithms for SAR data preprocessing.

This task will require a 2-3 man-year per year level of effort over a 5-year period.

TASK 3: Incident Angle Effect Correction

The objective of this task is to develop algorithms to reduce the effect of angle of incidence variations to provide nearly uniform images across the entire swath width.

The approach includes the following activities:

1. Define the angular dependence of backscatter for uniform agricultural scenes using field measurements and analytical techniques.
2. Process aircraft-acquired imagery over uniform crop/range or forest land with and without the angle effect corrections, and evaluate the processed data.
3. Determine the usefulness of the angle of incidence corrections through pattern recognition techniques.
4. Prepare angle of incidence corrections for spacecraft data, and test their usefulness using SIR-A data.

This task will require a 1-2 man-year per year effort over 5 years.

TASK 4: Atmospheric Effects Correction

The objective of this task is to develop and implement atmospheric effects corrections for SAR image data at various frequencies, polarizations, and incident angles.

The activities include:

1. Investigate and document various atmospheric data needed for radar data correction.
2. Develop correction models for SAR data based on measured atmospheric parameters.
3. Implement correction models in aircraft SAR preprocessing algorithms and evaluate data usefulness.
4. Develop preprocessing correction algorithms for spacecraft data and test these using SIR-A acquired data.

This task will require a 1-2 man-year level of effort over a 3-year period.

TASK 5: Sensor Effects Correction

The objective of this task is to develop and implement methods to calibrate SAR data to the required precision/accuracy needed for agriculture applications.

The activities include:

1. Survey parameters for each SAR used for agriculture data acquisition which cause calibration problems, these include sensor nonlinearities, antenna gain uncertainties, digitization, and truncation errors.
2. Develop a scheme to acquire data over man-made and homogenous scenes to calibrate effects of the indicated parameters.
3. Develop computer programs to correct these deviations in the data processing phase, and acquire aircraft data for evaluation.
4. Process aircraft-acquired data using calibration algorithms and evaluate applications potential.
5. Develop calibration scheme to be used for spacecraft SAR data for agriculture applications.

This task will require a 1-2 man-year per year level of effort over a 5-year period.

TASK 6: Software Development and Data Base Management

The objective of this task is to augment a current MSS data analysis software system to incorporate analytic algorithms into a programmatically useful computer software system for SAR data analysis. Major components such as disparate sensor data registration, disparate sensor resampling, accuracy assessment, angular effects correction, coherent noise treatment, sensor system parameter selection, etc., as developed for MSS analysis will require rework and revision to accommodate one or more information channels provided by SAR data.

The activities include:

1. Initiate implementation of a rectification/registration/resampling software system on the NASA/JSC main frame computer to enable the building of merged data sets in pixel-registered form from multiple combinations of aircraft SAR, aircraft MSS, and Landsat MSS data. Modify classification algorithms for including radar data.
2. Implement radar screening software system and approaches for spatial averaging of coherent noise/fading

effects to improve SAR signal-to-noise characteristics. Incorporate angle of incidence correction of backscatter and finish registration/resampling system.

3. Implement and test angle of incidence correction algorithms as developed under the data processing algorithm development.

4. Increase throughput rate of merging aircraft and MSS data and SAR data into registered resampled corrected multivariate data sets for classification.

5. Incorporate modifications to rectification, registration, resampling, noise averaging, angle corrections as necessary from problems identified in multisegment test of preprocessing and classification algorithms.

This task will require a 4-6 man-year per year level of effort over a 5-year period.

RECOMMENDATIONS

1. The experiments outlined by the Agriculture Panel share a common characteristic: several institutions and agencies are involved. Such an array of programs demands the formation of a research coordination team(s). The teams would, of course, be responsible for routine coordination of the various projects. But, as important, the team would oversee the data calibration and verification activity and supervise the merging of all data into a credible base. The problems of merging and comparing visible/infrared and radar data are not trivial. Successful experiments of this nature require close and frequent communication among the participants.

2. The general problem in applying microwave sensor data to agriculture systems is a lack of understanding of the interaction of electromagnetic energy with vegetation systems. The vegetation system associated with agriculture, forestry, and range are each different in geometry, electrical properties, and statistical distribution. Very little work has been done in attempting to describe the physical model which drives the interaction process.

Only recently have volumetric models been developed in an attempt to describe this interaction process. Unfortunately, very little high quality data are available with which these models can be effectively evaluated. The quantitative use of radar data in any application to agriculture, hydrology, land use, etc., must be built on a firm foundation of an understanding of the principles governing the interaction processes.

An evaluation of the capability, or lack thereof, of SAR data in a particular application cannot rest on a program based on empirical analogy. This axiom is not peculiar to the microwave application research, but to scientific research in general.

NASA should make a firm commitment to a research program which includes an approach to describe the scene/energy interaction problem. This includes a strong coordinated modeling effort (interaction phenomena) combined with experimental programs designed to collect model verification data using truck based instrumentation.

3. Research and development programs in the past have frequently been only moderately successful because funding support has been at an inadequate level to fulfill needed objectives. Fragmented programs conducted under different time frames and with limited equipment and objectives generally cannot be assimilated into a coherent set of conclusions, and result in inefficient use of funds.

4. It is recommended that careful consideration be given to providing adequate support to meet justified program needs such as:

a. Multispectral and multi-stage investigations including visible, infrared, and radar data.

b. Multidisciplinary investigations including adequate representation of resource and systems scientists and engineers.

c. Coverage of sufficient test sites to meet program objectives involving variable site conditions.

d. Provision for temporal coverage to assure studies of resource and climate variables which change with time.

5. NASA should extend current truck-based systems to include L-band and X-band, multi-angles, and multiple polarizations (like and cross-polarization).

NASA should fund the construction of more truck systems so that long duration, high temporal sampling experiments can be carried out in multiple sites and by multiple investigators. The changing (dynamic) crop condition demands continuous monitoring for research purposes. The credibility of results increases sharply when multiple investigators and research institutions are working the same problems and getting the same results.

6. NASA should fund development of dedicated helicopter or aircraftborne radar systems for agricultural remote sensing application development.

7. Worldwide monitoring of food production could provide information of great importance to policy decisions of many nations. A primary use of Landsat data has been in estimating the areal extent of crops, with a start towards an evaluation of crop condition. Although successful, Landsat is severely limited by clouds, which prevail over many parts of the world. Thermal infrared data adds another dimension to reflected data, but is again limited by clouds. The combination of the three regions forms a framework for the development of an all weather remote sensing system that could identify and measure the areal extent of crops, provide a crop condition assessment, an early warning of changes in crop condition, and provide frequent real-time inputs into yield prediction models.

The molding of information from the three regions into an all weather system requires the construction of a data base for relating spectral response from the several regions to the pertinent agronomic parameters, such as plant density, leaf area index, biomass, crop architecture, crop geometry, and plant physiological measurements that provide an index of stress and its consequential effect on yield. This task can only be done by a multidisciplinary team composed of engineers with backgrounds in instrument design and operation, and agricultural researchers with backgrounds in soil and plant science. The team should design a series of multitemporal, multiple location ground and aircraft experiments using sensors from the three spectral regions over the same targets at the same time, with the soil and plant scientists providing contemporary measurements of the pertinent soil, plant, and environmental parameters.

The final task of the team would be to synthesize the data and propose a system that could provide a worldwide crop monitoring capability.

8. NASA should continue to sponsor regular workshops, symposia, and research meetings to provide a forum for exchange of data and results and for review by the scientific community.

SUMMARY

The Agriculture Panel of the ERSAR Program Definition Working Group proposes that an intensive basic and applied research effort be conducted to assess the extent to which active microwave data can be used with and without visible/infrared data. A 70-100 man-years level of effort per year for a five year period is recommended to identify major crops and to measure their area; to assess crop condition and to predict crop yield; to assess and to predict crop growth stage; to identify major forest vegetation types and to map their areal extent; to identify and map rangeland vegetation; and to detect and map saline soils. The effort is balanced and phased to progress from laboratory and small field experiments to determine scene/radiation characterizations, through large area (5x10km) testing of algorithms and application of pattern recognition and image analysis techniques, to a set of mission and system specifications for an optimum synthetic aperture radar configuration to support agriculture information needs.

LAND COVER

RESEARCH NEEDS

The implementation of the program defined here is critical to the establishment of an organized, coherent data base for land cover investigations with active microwave data. The potentially unique and complementary nature of active microwave for characterizing land cover data must be addressed. How important is the potential of radar data for enhancing cultural features? What is the real value of the textural information content of radar data of urbanized areas? Can steep depression angles and sensitivity to soil and vegetative moisture parameters really help improve classifications of forested wetlands? These questions beg research answers. To answer these questions, data sets must be obtained (including spectra from trucks, aircraft, and spacecraft); better processing and analysis techniques must be developed; and the rigor of assessment methodologies must be improved. Successful accomplishment of these tasks will provide the basis for a valid assessment of the true potential of active microwave systems for meeting user-defined land cover data needs.

The Land Cover Panel believes it is imperative that efforts be initiated to:

1. Establish a set of models to characterize the relationships between radar backscatter measurements and land cover elements in a variety of environments;
2. Improve the understanding of the effects of active microwave system parameters on the ability to accurately classify land cover types;
3. Improve the understanding of the influence of environmental changes on radar backscatter measurements; most importantly,
4. Develop a set of preprocessing and classification algorithms to take maximum-advantage of the potentially unique character of active microwave data for land cover analysis; and
5. Assess the cartographic potential of active microwave data with respect to national map accuracy standards.

This section defines a research program to assess the potential of active microwave data in meeting specific land cover information requirements. It includes a prioritized assessment of the potential of active microwave data (given sufficient research), used either alone or in conjunction with data from visible and infrared sensors, for improving the quality of current land cover information derived from remotely sensed data. This increase in data quality may be related to improvements in either the accuracies with which individual land cover elements can be classified, or the potential for deriving timely, accurate inventories of land cover parameters. Emphasis is placed on urban and forested wetland area boundary definition, and urban land cover categories. Included is an analysis of radar parameters such as spatial resolution, azimuthal look direction, wavelength, polarization, and incident angle. It must be emphasized that owing to the lack of adequate data sets on urban areas, little can be said concerning optimum frequencies, look angles, polarization, etc., for maximizing extraction of pertinent land cover data.

Land cover data are needed as a base for information systems devoted to all aspects of resource management, conservation, and allocation activities. Included are such aspects as energy use, disaster recovery and prevention, environmental monitoring and developmental impact assessment.

At present there is no coherent body of information that documents the potential and contribution of active microwave data for obtaining land cover data. It is acknowledged that radar is the only sensor that can systematically acquire data in cloud covered environments, low light environments, and in cases where time is a critical factor, e.g., disaster extent and relief programs. Although alternative systems have been suggested to alleviate this situation, microwave research should proceed until such time as these systems prove their potential for supplying needed information to users.

The purpose of this research program is to establish what information can be extracted from data acquired by active microwave sensors for specific land cover categories by type and level of detail. Currently, it is not known what, if any, unique contribution can be made by radar as compared to other sensors, or if it may be of use only when other sensors cannot obtain data. However, the potential of radar data for enhancing object-to-background contrasts of man-made targets; its possible potential for adding important textural information for classification of urban and rural urban fringe zones; and its potential for aiding and improving the accuracy of classifications of forested wetlands, deserves research attention. If radar does provide unique data, it is imperative that the type, nature, and degree of utility of that data be accurately determined. This will require both the continuation of current land cover research efforts, as well as the initiation of new research in a number of areas.

The recommended land cover research program addresses the land cover data needs discussed in the ERSAR Applications Working Group Report. The Applications Working Group felt that three important applications areas should be addressed:

1. Comprehensive mapping of current land use/land cover patterns;
2. Surveys of specific land use/land cover types for natural resources planning and management; and,
3. Disaster monitoring.

The user community for land use/land cover information is very broad. It includes: (1) planners at Federal, State, and regional levels, as well as in the private sectors; (2) resource managers; (3) researchers in academic, industrial, and government areas; and (4) a variety of business people and educators. In addition, it must be recognized that there is an international demand for these data as well as a domestic one.

Improved comprehensive land cover cartographic information is required to increase the usefulness of resource maps utilizing the U.S. Geological Survey mapping scheme developed in USGS Professional Paper 964. More complete Level II category classification is needed for users at the Federal, State, and local levels.

Timely data are required by resource planners and managers to facilitate the development of regional data bases where data are collected and analyzed over large geographic areas within a narrow time window. Current land cover information is required for the 300 major metropolitan areas throughout the United States. In many areas, large area coverage over multiple swath-widths is required within a three-month period to support a number of state and federally mandated data base programs. Cloud-free coverage will continue to be a major element in the uniform collection of the resource information over large areas until such time as either geosynchronous or high resolution orbiting systems can close this portion of the data gap. An active microwave system might be required to provide all data of a given area in times of severe cloud cover to meet a given time schedule for inventory. It is emphasized again here, as in the earlier report, that most often such a system would be employed to assist in the extrapolation of information collected and analyzed in land use/land cover in the visible and near-infrared region from cloud-free areas to cloud-covered areas.

Finally, with respect to disaster monitoring, frequent surveys of disaster areas are required for satisfactory estimation of the intensity or extent of damage. This requires the ability to monitor the site through cloud cover, dense smoke, and at night. Such phenomena as tornados, hurricanes, floods, forest and range fire damage, and coastal shoreline overwash by storm surge waves require monitoring. If information on the type and extent of damage due to such disasters is important and this type of data needs to be rapidly obtained, then a persuasive case for research on the

potential for obtaining pertinent land cover data from microwave systems under such conditions can be made. This is so even given the potential for high resolution visible and infrared sensors, or the possibility of high resolution geostationary platforms. What is critical is the need to know if active microwave data will give an adequate assessment of the state of the land surface upon which relief or mitigation decisions can be made.

In order to address these needs, the Applications Working Group identified a number of investigations to be performed in a phased approach. These investigations include analyses of:

1. Ground-based versus airborne versus spaceborne active microwave data.
2. Investigation of the impact of radar systems parameters on land use/land cover signatures.
3. Assessment of the cartographic accuracy of SAR.
4. Simultaneous multi-parameter SAR investigations.

They concluded that: "several important resource application areas have been identified that could benefit from utilizing SAR data in the mapping scheme." The Applications Working Group recommended that NASA develop a series of experiments which would provide a quantitative evaluation of the potential application areas identified in their report. Additional requirements are:

1. Distribute Seasat SAR data to a wider user community.
2. Develop a spaceborne SAR program as a means of continuing to furnish microwave image data compatible with Landsat-D data.
3. Support the development and evaluation of MSS and SAR data integration and thematic classification techniques for land cover/resource mapping.
4. Evaluate multi-channel and multi-polarization imagery for its potential improvement to land cover mapping over single channel SAR data.

A summary of the findings of the Applications Working Group concerning the information needed to establish the utility of active microwave data listed two major research drivers:

1. Document the potential of radar image data used independently and/or in conjuction with visible/infrared image data for improving urban area boundary delineation and urban land cover classification accuracy in both manual and automatic mapping and thematic classification. Included here would be an analysis of radar parameters such as resolution, azimuthal look direction, wavelength, polarization, and incident angle.
2. Establish the value of radar/Landsat composite data for improved land cover/land resources mapping with emphasis on multi-frequency, multi-polarization radar data.

The recommended research program plan addresses these research topic areas in a coherent manner.

To date, most research which has been conducted has not focused on land cover analysis. What research does exist in the land cover area has been gleaned from various sources, almost in a random manner, as an addendum to projects devoted to other earth resources investigations. It is only through the efforts of independent investigators, operating with their own or very limited funding that the present, limited data base exists.

Given the need to acquire land cover information as an end product and as a data base for related earth resources analyses, e.g., energy studies, coastal zone management, urban growth, environmental monitoring, it is imperative that an organized research program be initiated.

APPROACH

To provide a basic definition of land cover for use throughout the land cover research program described below, the land cover classification system defined in USGS Professional Paper 964 (Table 4) was adopted. Level II was selected as the appropriate level of detail to work towards in this research program.

Theoretical and empirical active microwave research in nonurban land cover, e.g., crop land, rangeland, forest land, water, will be addressed to a large extent by the other panels. Much relevant land cover data gained through research in these areas can be extrapolated for use by those involved in NASA and other related land use/land cover research programs. Therefore, the primary concern of this panel has been the development of experiments which focus primarily, but not exclusively, on the urban/suburban and urban fringe zones and wetlands areas not currently being investigated in any consistent fashion. These areas, however, are of critical concern to resource managers as both the habitat of man, and of many rare and endangered species.

Within the land cover category classification scheme employed, priority should be given to the following elements:

1. Residential.
2. Strip and clustered settlement.
3. Open areas and transition areas on the urban fringe.
4. Extractive activities.
5. Vegetated wetlands.

TABLE 4. LAND-USE CLASSIFICATION SYSTEM FOR USE WITH REMOTE SENSOR DATA[a]

LEVEL I	LEVEL II
Urban and built-up land.	Residential.
	Commercial and services.
	Industrial
	Extractive.
	Transportation, communications, and utilities.
	Institutional.
	Strip and clustered settlement.
	Mixed.
	Open and other.
Agricultural land..	Cropland and pasture.
	Orchards, groves, bush fruits, vineyards, and horticultural areas.
	Feeding operations.
	Other.
Rangeland..........	Grass.
	Savannas (palmetto prairies).
	Chaparral.
	Desert shrub.
Forest land........	Deciduous.
	Evergreen (coniferous and other).
	Mixed.
Water..............	Streams and waterways.
	Lakes.
	Reservoirs.
	Bays and estuaries.
	Other.
Nonforested wetland.........	Vegetated.
	Bare.
Barren land........	Salt flats.
	Beaches.
	Sand other than beaches.
	Bare exposed rock.
	Other.
Tundra..	Tundra.
Permanent snow and icefields.......	Permanent snow and icefields.

[a]Classification system defined in USGS Professional Paper No. 964 (1976).

These are the land cover components about which it is believed active microwave data can contribute information because of the unique nature of active microwave data, e.g., sensitivity to moisture in the case of wetlands, the potential for providing unique textural information in urban, strip and clustered, and open and transitional areas. These types of information, particularly those dealing with the urban and rural/urban fringe, are important for planning purposes and as input to environmental monitoring and change detection models. Moreover, they are components that, because of their geometry, morphology, and texture parameters, may prove most susceptible to analysis using active microwave data.

The surface texture component obtainable with imaging radar sensors, when added to the conventional multispectral thematic classification schemes, may provide two important inputs: (1) category boundary delineation where field and roadway boundaries that enclose and characterize each land cover category are sharply delineated; and (2) improved category classification accuracy due to the potentially unique texture component in active microwave sensor data that may be added to visible sensor data. The surface texture component is particularly suited to assisting the identification and boundary delineation of cultural patterns on the landscape. As the patterns produced by human activity differ from those occurring naturally, i.e., more straight lines with angular surfaces of more uniform dimensions, active microwave sensor data appear to offer the potential for assisting in the accurate, timely delineation of urban land cover types.

Development of change detection techniques for the monitoring of residential expansion in the urban fringe zone is a requirement that is mandated by the U.S. Bureau of Census. Delineation of this urban fringe zone is used as a basis for the distribution of monies to local governments from a number of federal funding programs. As stated above, as naturally-developed and culturally-derived components typically produce shapes of different types, boundary delineation could potentially be assisted by the addition of active microwave data. The potential accuracy improvement derived through the addition of such a system, however, needs to be addressed in a coherent research program.

Monitoring the conversion of agricultural lands to urban development is of considerable interest to the resource manager. Conventional Landsat multispectral classification has limitations due to the similarities in spectral signatures of residential areas and certain agricultural practices. Here again the geometry of cultural features is significant and until such time as it is proved that higher spatial and spectral resolution visible sensors can adequately resolve these conflicts in classification with acceptable accuracies, active microwave research should address this important user data need.

Improved identification and inventory techniques are needed to map surface strip mines in the eastern and western regions of the U.S. This information is required on both the federal and state level. Landform identification and terrain analysis are required as input to the area strip mining data base. The ability to evaluate the excavation and reclamation activities over a large geographic area is also a user data need. An important element in this extractive category is the identification of abandoned mine lands. Reclamation requires the ability to identify altered surface topography such as contour mining and mountain removal, through regrown vegetative ground cover. This may be aided by a surface texture element in the spectral classifier, which can be achieved with radar data. The federal government is placing a tax on each ton of coal to provide a multimillion dollar fund for the reclamation of the abandoned mine lands.

Forested wetlands identification and mapping require the delineation of basic species level data: deciduous, coniferous, and mixed. Surface texture data could provide additional information related to height and density of vegetation as associated with varying water regimes and, therefore, enhance the accuracy of delineating forested wetlands. Accurate delineation of coastal wetland boundaries hinges on the ability of radar to penetrate vegetation cover (marsh or floating aquatic plants), and indicate whether the underlying surface is land or water.

Existing techniques of marsh/wetland productivity estimation provide for delineation of different species of marsh grasses, but fail to detect the inundating standing water beneath the marsh grasses. The inundating water boundary is a significant parameter that affects marsh productivity. Microwave data may provide the boundary of wet and dry marsh and thereby lead to a more accurate estimate of the productivity of marsh grass areas.

The panel believes that three major components of the radar/land cover interface must be explored to document the utility and potential contribution of radar data for land cover analyses:

1. The relationship of radar system, environmental, and time parameters to land cover mapping information;
2. Improved preprocessing and classification procedures to facilitate the extraction of critical data uniquely available from active microwave sensors, e.g., textural information, information of the presence of moisture, enhancement of man-made structures; and,
3. Cartographic properties and planimetric accuracies of radar data.

The first two tasks are considered top priorities in assessing the role of radar for land cover analysis. Only after the texture/geometry contributions of radar data have been established will the methods and problems of cartographic display be pertinent. However, the third task will be critical regardless of the nature of these findings. Much of the work of the other panels will require cartographic (map) display. Moreover, if radar data are to be integrated with a merged into (along with other sensor and ancillary data) geo-based or geo-referenced information systems for modeling and analysis, the techniques and procedures for registering such multidimensional data to a common base must be defined and addressed. For these reasons, the third task should be pursued independent of the results and conclusions derived from the first two tasks.

TASKS

The research program envisioned by the Program Definition Working Group Land Cover Panel is comprised of three distinct but interrelated tasks that address the data needs laid out by the ERSAR Applications Working Group. Each research task is dependent upon the other to fully assess and comprehend the utility of active microwave data for land cover data studies. The level of detail and category classification system employed by the Land Cover Panel is designed to utilize data obtained from research conducted by the other panels to as great an extent as possible, e.g., crop land, pasture, and rangeland data can be extrapolated from the Agriculture Panel program. The decision to focus efforts on urban/suburban and wetlands classification and in the urban fringe zone is based on this fact: no other panel will likely adequately address the active microwave research needs in these areas of critical concern. Concommitantly, results of the recommended theoretical and empirical research can be adapted readily to non-urban land cover data.

Foremost in the understanding of the radar backscatter signal in urban/suburban and wetland environments is the collection of airborne and/or helicopter scatterometer data. No empirical data of this type exists for such environments; making interpretation of subsequent active microwave imagery difficult. Therefore, there is a strong need for a thoughtful field spectra effort in order to model and understand the complex nature of active microwave returns in these environments.

Second in priority is the acquisition and wide dissemination of comprehensive active microwave multi-parameter

data sets to test hypotheses. These data sets should be developed over time in conjunction with the field spectra data acquisition program, and be comprised of both aircraft and spacecraft data for selected test sites. The choice of test sites with respect to their physical and cultural diversity is critical. If properly done, this will allow determination of whether or not various radar parameters have dramatic effects on data/information derivation potential when such parameters are applied over diverse environments.

Active microwave data must be successfully incorporated with other remotely sensed and ancillary data if it is to be useful for land cover mapping. The current knowledge of digital SAR preprocessing and its use in pattern recognition procedures is woefully inadequate. A considerable research effort will be required to identify those preprocessing and classification algorithms which are optimum in extracting the maximum land cover data from radar data, and for incorporating radar data into the mainstream of other land cover inventories. Preprocessing challenges include, among others: (1) how to rectify SAR data to other data sets, and what is the RMS accuracy expected; (2) what preprocessing algorithms are ideal to create radar "feature" images which maintain the important surface roughness (textural) data as spatial information; and (3) what new or hybrid classification algorithms, e.g., combining maximum likelihood with syntactic, can be developed to use the unique data present in these preprocessed radar data in a more effective and efficient manner?

TASK 1: Relationship of Radar System, Environmental, and Time Parameters to Land Cover Mapping Information

The objective of this task is to provide an active microwave multi-parameter data set, complemented by more conventional sensors (1) of urban and rural/urban fringe areas through time in diverse environmental and morphological settings, and (2) of forested wetland areas to determine the impact of various radar system parameters on the data/information extraction potential of these high priority land cover signatures.

A two-stage approach is recommended:

1. Collect microwave spectra of urban and rural-urban fringe sites over a range from 2-18 GHz and at different look directions, polarizations, and depression angles for a set of Level II land cover categories using an airborne or helicopter mounted spectrometer.

2. Operate a complete multi-parameter complement of existing microwave sensors systems, e.g., airborne X, K, and L-bands, over eight North American cities with diverse biocultural environments and physiographic settings at different seasons. Microwave system parameters which maximize relevant information content will be determined. Interface mechanisms will be developed for combining radar and other types of remotely sensed data. Evaluation of the potential improvements to land cover classification made by the addition of radar data will be carried out.

At the present time, there are no active microwave spectra of urban and near urban areas to define optimum active microwave systems parameters and to model data content in a predictive fashion. This task will permit the effects of urban morphology and geometry to be modeled in a more meaningful way with respect to the potential of the radar textural component. In addition, potential channels of information unique to radar can be more effectively ascertained and tested in empirical investigations. For example, do diverse residential, commercial strip, and urban fringe areas have unique textural signatures that can be modeled; and, if successful, will this improve the potential for accurately characterizing these areas?

There is a need for a systematic analysis procedure for multi-sensor data sets for areas of land cover classified as urban, suburban, and wetland. To conduct such research and to reach valid conclusions, there is also a need to conduct the analyses on a diverse set of environmental scenes and temporal sequences, particularly within the realm of urban, suburban, and urban fringe land cover conditions. Through a uniform data collection technique, standardized procedures, and interface techniques, the environmental and temporal variables which can be measured with active microwave sensors can and will be quantitatively identified. Data sets obtained should be made available as open file data (at cost of production) to qualified scientists.

This task should provide a set of models of derived backscatter data to define optimum radar system parameters for airborne/spaceborne SAR systems for the generation of user defined data in the urban and near urban areas of the United States and eventually the entire globe. By modeling and predicting land cover spectra, simulated data can be compared with those data obtained by specific existing aircraft/spacecraft microwave systems (Task 2), and theory modified accordingly. Data can also be interpolated between known data points, e.g., K, X, L-bands, for scatterometer and aircraft data and for all intermediate active microwave bands. These data can then, if found valid and useful through verification of model results, provide the underpinnings for the design of future radar systems for long range land cover investigations.

Results of this research should also lead to an empirical determination of which active microwave systems parameters are optimum for Level II land cover classification. In addition, these data can be used to refine the knowledge concerning optimum radar system configuration over diverse environmental conditions. These conclusions will be derived from (1) a set of validated microwave system parameters ranked by their contribution to improved information content; (2) documented data overlay and integration techniques for microwave data; (3) a model for testing microwave data classification improvement for diverse cover types throughout the United States; and (4) standardized format for microwave data sets for eight test sites across the U.S.

An n - dimensional matrix can be utilized to define parameters for evaluation and prioritize parameters for evaluation and testing. Airborne radar systems should be flown at different seasons over the greater Los Angeles, Seattle, Atlanta, Houston, Washington, D.C., Indianapolis, Denver, and Toronto metropolitan areas. Available reformatting and overlay programs for registration of data sets will be tested. An automated georeferenced data base for test sites will be utilized to evaluate classification and land cover data improvements.

A 5-6 man-year effort, plus data acquisition and processing costs, is required over a 4-year period. The required helicopter-based sensor is a new development item.

TASK 2: Improved Processing and Classification Procedures for Radar Data

The objective of this task is to identify preprocessing and/or classification algorithms which optimize urban/suburban and wetlands land cover classification when SAR data are used as an input to pattern recognition procedures.

There has been a substantial discussion concerning the use of digital active microwave data as an additional data plane in pattern recognition procedures. Research results by JPL and NSTL personnel appear promising. However, the incorporation of radar as an additional channel will require further development to optimize the contribution of SAR data to overall land cover classification. The development of new, and improvement of existing algorithms is also essential in extracting maximum data content from SAR imagery for definition of textural contribution and for the effective analysis of merged multi-sensor data sets. In defining the potential of radar systems for land cover analysis, it is of critical importance that such software parameters be explored in the light of both systems and environmental variables.

The recommended approach is to:

1. Identify existing preprocessing and classification logic involving the use of digital radar data.
2. Evaluate existing methods on controlled data sets.
3. Develop improved preprocessing or classification algorithms as required.

This work will involve analysis of aircraft and spacecraft active microwave data and field spectra results. Active microwave data can be used in the pattern recognition procedure in one of two general formats. First, if multi-parameter SAR digital data are provided, it is possible, theoretically, to perform discriminant analysis as syntactic classification on the rectified data set. Second, the SAR digital data may be used as an additional spectral channel, along with other data such as Landsat. In this latter case, the microwave data could be either raw or preprocessed to derive an image of texture as it is defined in the pattern recognition literature. In either case, algorithms must be identified which make maximum use of the SAR image content. Specific elements of this problem are:

1. Identify existing preprocessing and classification procedures.
2. Obtain control active microwave data sets and/or other spectral data sets from the eight U.S. test sites.
3. Preprocess to "texture" and other features and apply classification algorithms to SAR data alone and in conjunction with other spectral data.
4. Assess classification performance by comparing with field verified test sites.
5. Based on results obtained and findings of the field spectra work described above, propose and test alternative preprocessing and classification algorithms.
6. Extend algorithms to each of the test sites to assess the influence of environmental change.
7. Prioritize preprocessing and classification alternatives for accurate, timely land cover inventories.

This work will document and prioritize preprocessing and classification procedures for improved urban/suburban land cover classification, as well as wetland monitoring and inventory. From these data, the potential of active microwave for hazard monitoring and for other related land cover applications can be documented. The panel believes that this software development must occur in conjunction with investigation of urban spectra modeling and system/environment parameters. Each is important in the definition of the types of information available through active microwave systems, particularly as they pertain to textural, backscatter, and feature geometry/morphology.

This task will require 12 man-years over a four-year period, plus 500 hours of computer time.

TASK 3: Cartographic Properties and Planimetric Accuracies of Radar Data

The objective of this task is to determine the map accuracy of multiple SAR image data sets over the same scene. A need common to all levels of applications of digital image data sets is geometric rectification to ground coordinate systems. The ease with which spaceborne SAR digital imagery can be co-registered with other earth observations imagery and other geo-coded data, will determine the rate at which it can be incorporated not only into land cover applications, but geology, agriculture, and other earth resource applications as well.

Ultimately, most earth resource information obtained from SAR data will be related to surface data or displayed in cartographic format. The drawing of conclusions from the imagery either in an operational or research application will, to a greater or lesser degree, depend upon the users' confidence that an observation in the SAR data can be located in map space and compared with other mapped data sets. In addition, geometric rectification is a necessary step if the SAR data are to be merged with complementary multispectral and ancillary data, e.g., Landsat, digital terrain, or seismic data.

At a minimum, an experiment should be performed to determine the feasibility of SAR image data to meet National Map Accuracy Standards at a scale of at least 1:250,000 and preferable 1:100,000. Test sites should include flat terrain, e.g., Houston, Texas; undulating terrain, e.g., Washington, D.C.; and mountainous terrain, e.g., Seattle, Washington. Seasat SAR and SIR digital data sets for each terrain type taken at different dates and for ascending and descending orbits should be analysed for the degree of local misregistration (RMS error) between ground control points that occur due to (a) orbit parameter calibration sensitivity, and (b) horizontal displacement associated with terrain. This will require a systematic analysis and programming effort to utilize digital terrain files to assist in compensating for horizontal offset caused by look angle, and to assist in providing an understanding of the limits inherent in topography compensation procedures. Specific elements to this task are:

1. Select test areas in association with the USGS Mapping Division.
2. Obtain Seasat SAR digital image data sets for test areas based upon latest approved calibration algorithms.
3. Determine RMS error of approximately 25 evenly distributed points over each SAR data set to which ephemeris calibration has been applied.
4. Apply co-registration of multi-date and ascending and descending data sets for each scene and determine RMS error of local misregistration between ground control points.
5. Model photogrammetric properties of horizontal displacements expected from spaceborne SAR systems due to topographic displacement and implement appropriate algorithms.
6. Apply digital terrain model compensation to SAR imagery and determine the degree of improvement in co-registration of the multiple SAR data sets with regard to RMS error of local misregistration between ground control points.
7. Determine compatability with other sensor systems and data types necessary to insure efficient co-registration of multiple data sets.

This effort should result in a definitive statement on the ease of multiple SAR data set registration and the RMS positioning accuracy to be expected under various terrain conditions for co-registration of digital SAR images obtained from space platforms with other space-derived imagery.

A critical element in the potential of radar data for land cover analysis is the ability to merge such data with other land cover data derived from other remote sensing systems, as well as existing traditional data bases. Moreover, the ability to display radar data in compatible map format for other earth resource applications, e.g., agriculture, forestry, water, is of equal importance. This task addresses and answers the question of the methods and techniques whereby radar data can be merged into multi-discipline geo-based earth resource information systems.

The effort required is about 2 man-years per year over a 3-year period, plus 300 - 500 hours of computer time.

EXPECTED RESULTS

If NASA adopts and vigorously pursues the Land Cover research tasks set forth in this document, the panel feels the following advances in the current state of knowledge will occur:

1. Establish a set of theoretical models that will define and characterize the relationship between radar backscatter and land cover types;
2. Gain an understanding of the effects of radar system parameters on the ability to define specific land cover types;
3. Improved understanding of the influence of environmental change on radar backscatter response for specific cover types;
4. Document optimum parameters for acquiring land cover data within specific environments; very importantly,

5. Develop preprocessing and classification algorithms as input to pattern recognition procedures; and,

6. Assess the ability of active microwave data to meet planimetric requirements specified by the National Map Accuracy Standards.

WATER, ICE, AND SNOW

The research needs set forth in the ERSAR Applications Working Group Report were used as a starting point for defining an experimental program to acquire information to establish the validity and usefulness of active microwave data for accomplishing water, ice, and snow applications. These research needs were reviewed and generally accepted. Additional needs were identified by this panel. In most cases, the panel attempted to establish application needs and devise experiments that would reveal the true information content of the active microwave sensors, and their relative importance compared to other sensors. The panel addressed the research needs in hydrology; soil moisture; snowpack properties; sea, lake, and river ice; and glaciers and ice sheets.

In the four major subgroups, specific experiments were defined to deal with the research needs identified. Within each of the subgroups, the experiments were prioritized on the basis of those expected to yield the greatest improvement in state-of-knowledge and importance to the discipline. Those priorities are:

Hydrology
1. Rainfall
2. Hydrologic Models
3. Runoff Coefficients
4. Spatial Variability and Scale of Hydrologically Homogeneous Areas
5. Flood Mapping
6. Groundwater
7. Watershed Characteristics

Soil Moisture
1. Basic Energy Interactions
2. Algorithm Development
3. System Verification and Spatial Testing
4. Spaceborne System Specification

Snowpack Properties
1. Monitoring and Modeling of Snowpack Characteristics

Sea, Lake, River Ice
1. Winter Pack Ice
2. Ice Edge
3. Summer Ice

Glaciers and Ice Sheets
1. Glacier and Ice Sheet Study
2. Polar Ice Sheet Soundings
3. Interpretation of Radar Altimetry Data

The specific objectives of the recommended experiments program for water, ice, and snow applications are:

1. Evaluate the measurement capability of active microwave sensors for improving the understanding of hydrological processes.

a. Assess the potential of active microwave sensors for measuring rate and areal extent of precipitation over land surfaces.

b. Assess the incremental effects (improvements or degradations) due to use of visible/infrared, passive microwave, and active microwave data when used in various hydrologic models.

c. Determine if specific sensors or combination of sensors can be used to remotely measure a runoff coefficient for use in lumped watershed models.

d. Develop methods to measure the spatial variability of hydrologic parameters and variables. Determine the scale (size) of hydrologic units that are important for various applications, and develop criteria for delineating areas that can be treated as hydrologically uniform.

e. Determine areal extent of flooding world-wide, and generate time-area curves of inundation (how long an area below selected elevators is underwater).

f. Develop methods for estimating parameters and delineating areas for conjunctive management of surface and subsurface water. Identify groundwater recharge and discharge areas in complex watersheds. Develop methods for conducting resource inventory of groundwater by identifying seeps and springs, and quantifying seasonal charges of groundwater elevation.

g. Develop a system to automatically measure the physical characteristics of watersheds, and to format these data for direct use in hydrologic models.

2. Establish that a useful estimate of soil moisture can be made with active microwave sensor data.

a. Determine the dependence of the permittivity of soils on soil texture, soil constituents (salinity, clay type), soil water state (frozen/unfrozen, soil water potential energy), and the measurement wavelength.

b. Develop analytical models of electromagnetic scattering and emission in the microwave region of the spectrum.

c. Develop and validate soil water budget and hydrologic models that accept remotely sensed data as input.

3. Determine the relative importance of active microwave sensor data in relation to passive microwave, thermal infrared, and visible/infrared sensor data for snowpack monitoring.

4. Document the capabilities of active microwave sensors to record operationally useful information on floating ice characteristics.

a. Develop techniques to acquire and convert SAR image data to useful information products in a time frame consistent with the dynamic nature of floating ice phenomena.

b. Develop methods to incorporate SAR image data into current ice models and operating systems in ice regions.

c. Determine the geophysical properties of ice that influence the behavior of radar backscatter from floating ice, including ice type, composition, and surface roughness.

5. Define the potential of active microwave sensor data for studies of glaciers and ice sheets.

This research program concentrates for the most part on providing a detailed understanding of the active microwave information content in each of the subgroup areas. Experiments are designed with the need for detailed, supporting ground-truth in mind in all cases. Interpretation of what the active sensors are recording can be no better than the knowledge of the surface conditions. In addition, the experiments should be carried out with several types of sensors (active, passive, thermal, and visible) operating concurrently over the same study area. This will allow a realistic interpretation of the relative importance of active microwave techniques compared to other remote sensing approaches.

The use of truck-mounted systems is strongly advocated in the soil moisture and snowpack properties experiments. Existing truck capabilities have to be upgraded and expanded to permit collection of adequate field data. The aircraft support called for will require an increased emphasis on the use of active and passive sensors flown in tandem, and an increase in aircraft hours available for these flights. Table 5 lists the sensors required for each experiment. Table 6 identifies the required platforms.

The Hydrology subgroup and the Soil Moisture and Snowpack Properties subgroups are closely interrelated. In most cases snowpack and soil moisture would be a subset of hydrology, but because of their significant importance and the positive potentials for using active microwave effectively in these areas, they are treated separately. These programs should be conducted in an integrated fashion because of the close relationships. The Sea, Lake, and River Ice subgroup is significantly separate from the others because it is conducted over water rather than land, the scale is considerably different, and frequency of coverage is generally greater.

By conducting the listed experiments, it is expected that a quantitative understanding of the effect of various

TABLE 5. SENSORS REQUIRED BY EXPERIMENT

	SAR	SCATTER-OMETERS	RADAR ALTIMETER	PASSIVE MICROWAVE	THERMAL INFRARED	VISIBLE
HYDROLOGY						
1. RAINFALL	x	x		x	x	x
2. MODELING	x	x	x	x	x	x
3. RUNOFF COEFFICIENT	x	x		x	x	x
4. SPATIAL VARIATION & SCALE	x		x		x	x
5. FLOOD MAPPING	x		x		x	x
6. GROUNDWATER	x	:		x	x	x
7. WATERSHED CHARACTERISTIC	x		x		x	x
SOIL MOISTURE						
1. BASIC ENERGY INTERACTIONS				x	x	x
2. ALGORITHM DEVELOPMENT				x	x	x
3. SYSTEM VERIFICATION	x	x		x	x	x
4. SPACEBORNE SYSTEM SPEC	x	x		x	x	x
SNOWPACK PROPERTIES						
1. MONITORING & MODELING	x	x		x	x	x
SEA, LAKE & RIVER ICE						
1. WINTER PACK	x	x	x	x	x	
2. ICE EDGE	x	x	x	x	x	x
3. SUMMER ICE	x	x	x	x	x	x
4. TOTAL PAYLOAD STUDY	x	x	x	x	x	x
GLACIERS & ICE SHEETS						
1. GLACIER & ICE SHEET STUDY	x					
2. POLAR ICE SHEET SOUNDINGS		x	x[1]			
3. RADAR ALTIMETRY STUDY			x			

1-USE RADIO-ECHO SOUNDER

TABLE 6. MEASUREMENT PLATFORMS REQUIRED BY EXPERIMENT

	GROUND DATA	TRUCK MOUNTED	HELICOPTER		AIRPLANE	SPACECRAFT
HYDROLOGY						
1. RAINFALL	x				x	x
2. MODELING	x	x	x	OR	x	x
3. RUNOFF COEFFICIENT	x	x	x	OR	x	x
4. SPATIAL VAR & SCALE	x	x	x	OR	x	x
5. FLOOD MAPPING	x				x	x
6. GROUNDWATER	x	x	x	OR	x	x
7. WATERSHED CHARACTERISTICS	x	x	x	OR	x	x
SOIL MOISTURE						
1. BASIC ENERGY INTERACTIONS	x	x				
2. ALGORITHM DEVELOPMENT	x	x				
3. SYSTEM VERIFICATION	x	x			x	x
4. SPACEBORNE SYSTEM SPEC	x				x	x
SNOWPACK PROPERTIES						
1. MONITORING & MODELING	x[1]	x[2]	x		x	x
SEA, LAKE, RIVER ICE						
1. WINTER PACK	x	x[3]	x		x	x
2. ICE EDGE	x	x[3]	x		x	x
3. SUMMER ICE	x	x[3]	x		x	x
4. TOTAL PAYLOAD STUDY						
GLACIERS & ICE SHEETS						
1. GLACIER & ICE SHEET STUDY	x				x	x
2. POLAR ICE SHEET SOUNDINGS	x	x			x	x
3. RADAR ALTIMETRY STUDY	x				x	x

1-FIVE GROUND TRUCK VANS INSTRUMENTED, ONE FOR EACH STUDY SITE
2-FIVE TRUCK MOUNTED MULTISENSOR SYSTEMS, ONE FOR EACH STUDY SITE
3-VANS CAN BE DEPLOYED VIA ICEBREAKERS

hydrologic and cryospheric variables on the active microwave response can be achieved. This will result in a significant improvement in the state-of-knowledge. At this point there is only a rudimentary qualitative understanding of the active microwave processes in this application area.

HYDROLOGY

RESEARCH NEEDS

The experiments program recommended in this research area addresses the needs defined by the ERSAR Applications Working Group. These are:

1. Determine the hydrologic significance of microwave measurements as affected by vegetation, soil type, roughness, and soil moisture.
2. Develop procedures to extract direct measurements of these four factors from remotely sensed microwave data, or develop a hydrologic equivalent that encompasses all four factors.
3. Investigate the size of hydrologically homogeneous areas that can be represented by single measurements.
4. Determine the scale of hydrologic units that can be lumped with predictable losses in sensitivity.
5. Investigate the possibility of measuring rainfall input to hydrologic areas with radar sensors. Two issues should be addressed:
   a. Determine effective isohyetal maps of rainfall input to large areas for water balance calculations (agriculture yield, drought, and water resource management.)
   b. Determine if real-time estimates of rainfall rates and/or amounts can be estimated for real-time flood forecasting.
6. Investigate the use of SAR in groundwater resource management. Three items should be addressed:
   a. Identification of groundwater recharge and discharge areas for general planning, as well as solid and liquid waste disposal.
   b. Resource inventory including springs and seasonal changes in groundwater elevation.
   c. Procedures for conjunctive management of surface and subsurface water.

APPROACH

The research needs call for two types of program activities: one devoted to description of hydrologic processes in terms that are compatible with area-extensive input data, and one devoted to determine the capability of active microwave sensors to measure the parameters which influence hydrologic processes. The program plans defines these two activities, which this panel recommends be conducted concurrently.

In view of the fact that at present there are few viable hydrologic models suitable for use with area-extensive remotely sensed data, it is mandatory that hydrologic model development and remote sensing capability be developed in concert. This requires the formation of a dedicated team of hydrologists and sensing researchers working together to accomplish the program objectives.

The hydrologists should be primarily concerned with conducting the program elements described below under the title, Description of Hydrologic Processes. The sensing researchers should be primarily concerned with the program elements entitled: Influence of Watershed Parameters on Radar Backscatter Measurements. Both groups should maintain close interaction because of the complex interrelationships between the two task areas.

TASKS

Description of Hydrologic Processes - This program activity has as an overall objective the determination on an approach to describing hydrologic processes in terms that are compatible with remotely sensed data inputs.

TASK 1: Sensitivity Study of Hydrologic Models

The objective of this task is to determine advantages and/or disadvantages of describing hydrologic processes with models structured to accept remotely sensed data as primary input.

The approach to be employed consists of systematically categorizing existing hydrologic models; identifying the input parameters required in each model and assessing the practicality of obtaining these parameters from remotely sensed data; and determining the sensitivity of the model to this change in the source of input data.

To date, no systematic study has been undertaken to assess the sensitivity of remotely sensed data, including microwave data, on the solutions to conventional hydrologic equations, or on the outputs of conventional hydrologic models. No studies have been undertaken to modify existing hydrologic models or develop new models to effectively use remotely sensed data, including microwave data. Until such comprehensive studies are undertaken, incremental improvements due to use of either visible/infrared, passive microwave, or active microwave data, independently or in various mixes, cannot be quantitatively assessed.

This task will require a 2-3 man-year effort over a two-year period.

TASK 2: Direct Determination of Runoff Coefficient

The objective is to test the hypothesis that specific remote sensing data or combinations of different sensors data, can be used to remotely measure a runoff coefficient for use in lumped models.

Microwave sensors appear to be capable of measuring the four characteristics of a watershed that control the amount and rate of runoff from rainfall: soil moisture, vegetation, soil structure, and surface roughness. These characteristics have not been previously measurable as direct input to hydrologic prediction and forecast models. Currently, there are no adequate models to use this type of information, even if it were measured on a routine basis. The capability of measuring areas instead of points creates the potential for determining an equivalent runoff coefficient from remotely sensed data. The general approach in this task will be to merge remotely sensed data from several sensors to form one composite signal. This signal will be used as the primary input data for a lumped system model that has been developed or modified to use this type of information. This procedure would be tested with hydrologic data from instrumented watersheds.

The ability of microwave energy to penetrate vegetation (or not penetrate depending on frequency, polarization, and angle), to respond to soil structure, to respond to surface roughness, and to respond to soil moisture, are perhaps the most important features for hydrologic applications. These are the four watershed features that affect runoff from rainfall. In the existing hydrologic procedures, these features are seldom measured directly, but are estimated according to arbitrary relative scales. The potential for measuring the features directly could be a significant breakthrough for improving hydrologic techniques. If successful, this procedure could provide an objective and cost-effective method for obtaining input data for design and operational hydrologic models.

This task is expected to require an approximate 20 man-year effort over a five-year period.

TASK 3: Investigation of the Spatial Variability and Scale in Hydrologic Systems

The objectives of this task are to develop ways to measure the spatial variability of hydrologic parameters and variables; to determine the scale (size) of hydrologic units that are important for various applications; and to develop criteria for delineating areas that can be treated as hydrologically uniform.

The research questions dealing with scale and spatial variability can best be studied with a series of coordinated ground, truck, aircraft, and satellite experiments. Detailed ground measurements will define the spatial variability of the hydrologic characteristics that will have been selected for study. These characteristics will be measured from the various remote sensing platforms, and a set of data will be developed that will depict decreasing (degraded) resolution; but at the same time averaging or integrating the point measurements into a single response for sequentially larger areas. One or more distributed hydrologic simulation models will be used to take these data as inputs, and the simulated results will be compared to each other and to measured watershed responses. The comparisons will be the basis for evaluation of the hydrologic significance of spatial variability, and the scale of hydrologic parameters and variables that is important.

Remotely sensed data have a feature that potentially has great benefit for the water resource community, that is, the ability to measure an area, rather than a point. Hydrologic concepts have been developed from point measurements, i.e., soil columns, rain gauges, etc. As a result of this, hydrologists have been largely unsuccessful in treating spatial variability. This is perhaps the single most important reason why infiltration theory has not been successfully adapted for hydrologic procedures.

Remote sensing has the potential for "averaging" a great deal of information over an area. Use of these type data may provide the motivation for using more physically based models. However, it is likely that such models will have to be adapted or new models developed to take advantage of these data.

This task is expected to require approximately 20 man-years over a five-year period.

TASK 4: Direct Determination of Watershed Characteristics

Remotely sensed data have been used to determine some watershed characteristics, such as land use. The potential exists for determining directly many more watershed characteristics that could be used as input data for hydrologic models and management. To determine what characteristics can be measured and monitored by remote sensing, various sensor characteristics should be evaluated with respect to their ability to provide information on these watershed features. Several areas with adequate ground data should be selected and test flights made to provide data for chosen simulation models. The watershed features that may be measurable by remote sensing include, but are not limited to:

1. land cover and use,
2. canopy density,
3. channel network,
4. erosion features,
5. surface roughness,
6. wetlands and swamps,
7. topography slopes, etc., and
8. channel geometry.

In the past hydrologists have been limited to using lumped parameter models because distributed models were only practical in a research mode. The reasons for this are twofold: first, the type data required for distributed models require a great deal of labor and fields surveys; and second, there are really no criteria to decide how much detail is needed in preparing data for a distributed model. Both of these points can potentially be solved by remote sensing in a cost-effective way. If this can be done, it may open the door for widespread use of physically sound, distributed models. This type of model can provide a mechanism to evaluate land use and management alternatives without the trial and error approach that has been used in the past.

If this research shows that most watershed features can be measured directly by remote sensing, it will enable widespread use of complex distributed models for water and land management. It is conceivable that a totally automatic system could be developed to generate all the input data (except for state variables) for a watershed management model from satellite or specific aircraft flights.

This task is expected to require an approximate 10 man-year effort over a five-year period.

Influence of Watershed Parameters on Radar Backscatter Measurements - This program activity has as an overall objective to quantify the measurement capability of active microwave sensors for selected watershed parameters. It is known that active microwave sensor data can provide useful information on several parameters that characterize watersheds. However, many of these, e.g. land use, canopy cover, can also be obtained from other sensor data. This program activity concentrates on those parameters for which active microwave data have a unique potential. Primary among these are rainfall and soil moisture. The tasks required to address soil moisture monitoring are discussed later in this report.

TASK 1: Determination of the Potential of Microwave Sensors to Measure Rate and Areal Extent of Precipitation over Land Surface

Runoff is generally the single most important factor affecting water resources management schemes (e.g. flow controls, drainage design, water supply, hydropower, etc.). Precipitation is usually the single most important hydrologic variable in runoff calculations. Therefore, more accurate and timely precipitation measurements, especially in areas of sparse rain gauge returns, promises to produce high benefits.

The high benefits that would result from new improved methods of measuring areal extent and rate of rainfall overland, justifies a high-risk feasibility study of microwave sensors.

Rainfall is conventionally measured by in-situ gauges; about 25,000 in the U.S. and perhaps 100,000 throughout the world. WMO criteria for rain gauge densities are unlikely to be met in most areas of the world including much of the U.S. land surface. Landbased weather radar coverage is mostly complete over the U.S., however rainfall estimates based on these data are grossly inadequate for most hydrologic purposes, although radar estimates appear operationally useful in some locations for weather forecast purposes. Recent studies of Landsat and NOAA scenes suggest marginally useful rainfall information for hydologic purposes. However, the limitations of present spaceborne visible/infrared sensors, e.g. interference due to clouds, ambiguous determination of the areal extent of rainfall, lack of rainfall intensity information, seriously limit their usefulness for hydrologic purposes.

This task should include theoretical studies of both passive microwave and active microwave measurement concepts. The active microwave sensor approach using the Multiple-Beam Antenna conceived by Goddard Space Flight Center appears to have promise. A series of aircraft tests using a simple, single-beam radar designed to blank the terrain return, should be conducted to test this concept.

This task is expected to require a 10 man-year effort over 5 years, and funds for a modest hardware development.

TASK 2: Flood Mapping

Remotely sensed data have the capability of monitoring the extent of floods and their duration. Characteristics of potential sensors, resolutions, platforms, orbits, and frequency of observation should be evaluated. Systems for accomplishing these objectives should be tested with simulation models and criteria developed for a flood mapping system. The resulting systems concept should be documented with specific criteria for all weather capability, resolution, frequency of sampling, sensor characterisitics, data reduction needs, platform, and orbit. Simulation with

existing data and synthesized data should be able to define these parameters.

This task is expected to require a 3-5 man-year effort over a two-year period, plus the cost of associated experimentation.

TASK 3: Groundwater Resource Analysis

The objectives of this task are to identify groundwater recharge and discharge areas in complex watersheds: to develop methods of conducting resource inventory of groundwater by identifying seeps and springs and quantifying seasonal changes of groundwater elevation; and to develop methods for estimating parameters and delineating areas for conjunctive management of surface and subsurface water.

Delineation of groundwater recharge and discharge areas is an important aspect of any land management program. Selecting areas to meet certain objectives regarding control of pollution of surface waters and groundwater would be enhanced with this capability.

Conventional methods of groundwater assessment are time consuming and costly. Any procedure that could do this more efficiently would be extremely helpful in conducting and periodically updating this inventory.

Conjunctive use of groundwater and surface water is a new concept that is just beginning to be developed. To plan and manage such complex systems will require new types of information to characterize the aquifers and the aquifer-channel geometry. Remote sensing, particularly microwave remote sensing, appears to have this potential.

This task should require at least a 20 man-year effort over a five-year period.

SOIL MOISTURE

RESEARCH NEEDS

Soil moisture, whether measurements are required near the surface or are for the entire soil profile, is one of the most dynamic renewable resources measurements challenging the remote sensing community. Although the need for soil moisture information differs somewhat between hydrologic applications and agricultural applications, the research program required to address the capability of active microwave to measure soil moisture is practically identical. Hydrologists are primarily interested in the state of the soil, i.e., saturated to dry, in the near surface layers since this influences the amount of infiltration and runoff that can be expected as a result of a moisture input event. Agriculturalists are interested in the soil moisture profile down to the root zone depth and its relationship to crop yield. The major difference between the two requirements is the less severe requirement of hydrologic applications for accuracy and depth of measurement. Because of the dynamic situation involved with soil moisture, at certain times of the year, the hydrologic and agricultural applications may have the same depth and frequency of measurement needs.

In summarizing the need for information, at least the following variables must be realized:

1. Dynamic - Highly repetitive observations are necessary due to naturally occurring, rapid changes in moisture which are difficult to assess by any other means than remote sensing.

2. Extreme spatial variation - Within very short distances, variations may occur from flood to drought, therefore a successful sensor(s) must have the capability to assess the extremes under a variety of land surface conditions.

3. Surface cover - Due to cultural activities in agriculture, a varying degree of surface roughness commonly occurs at the soil surface.

4. Soil roughness - Due to cultural activities in agriculture, a varying degree of surface roughness commonly occurs at the soil surface.

5. Soil properties - Spatial variations in soils exist which affect measurements with certain types of sensors/spectral intervals. The measuring technique must be flexible and usable even under this variety of conditions. These include such factors as soil texture, soil layering, salinity.

6. Depth measurement - Soil profile moisture can potentially be used beneficially by plants to the rooting depth of the plants. This rooting depth is a function of many factors, but plant species and growth state are major contributors.

7. Inadequacy of present ground measurement techniques - Considerable effort must be extended presently to accurately monitor profile moisture temporally over even a small region. This adds to the need for developing remote sensing procedures, but also creates difficulty in evaluating these procedures adequately. Measuring devices which are sensitive to these and other extraneous variables will cause inaccuracies in the data and limit its usefulness. Therefore, any approach to develop a remote measuring technique must be cognizant of the variables causing measurement inaccuracies; must assess the effect of these variables; and must attempt to reduce associated errors.

Radar studies show promise for a direct measure of moisture, however, they have not been thoroughly evaluated. An integration of these study results appears difficult since data were not acquired or evaluated under consistent conditions. In summary, limited results are available suggesting that remote measurements in all spectral regions show association, either directly or indirectly, with soil moisture. Results are inconclusive and if investigators were requested to design a monitoring system, the number of systems specified would probably correlate with the number of investigators asked.

The array of information needs is broad. In many disciplines/applications, it is not possible to precisely specify the needs of accuracy, temporal, or spatial specifications because models are not present to use these data, since the data have not been previously available. However, basic to the question of needs to satisfy, answers to very basic questions must be available. Under an extreme diversity of conditions, is it possible to develop a technique incorporating SAR and other spectral data together with modeling that can:

1. Define the nature of soil water measured, i.e., tensiometric, volumetric, gravimetric;

2. Produce quantitative estimates at known depth increments;

3. Define the maximum depth for which measurements are accurate; and,

4. Be applicable over a wide variety of surface conditions.

Considering the above needs and the present state of knowledge which is fragmented by variations in experimental methods, site specific nature of observations, and inconclusive definition under a variety of conditions, inability to accurately define and measure the soil moisture variable, an integrated experimental approach should be devised A well controlled test site in the simplest environmental condition should be selected for in-depth use of a multiple sensor system. After development and testing of the models at the single site, added diversity of soil/climate/vegetation should be evaluated, most probably with an irrigated, rainfed test site in the Southwest U. and the Great Plains, and a rainfed test site in the Eastern U.S. under forested and non-forested conditions. These sites should be selected in reference to existing stations, i.e., Agricultural Experiment Stations where precision lysimeters and soil moisture and water budget experiments are ongoing. All systems and field methods should be consistent with evaluations of frequencies, angles, and polarizations of SAR with ancillary multispectral data, with a common method for field characterization. The observations must be combined with a soil profile model of moisture and temperature. Such a model is not presently available and must be simultaneously developed.

APPROACH

The research needs listed under Soil Wetness in the ERSAR Applications Working Group Report provide a good summary of basic questions that must be answered before it can be "scientifically" concluded that a useful estimate of soil moisture can be made with active microwave sensors. It should be noted that the needs addressed by the Applications Working Group addressed both the soil moisture needs of the crop yield problem and the hydrologic watershed runoff problem. The research program outlined here addresses both of these. Obtaining the moisture information needed in the crop yield problem is potentially the most difficult task, since it is currently believed that greater sensitivity and accuracy as well as depth interaction are required than for hydrologic applications. It is important to realize that even if these more difficult requirements are not met, the less difficult hydrologic requirements of near surface soil wetness conditions (saturated, mid-moisture, dry) could be of use to runoff applications.

It is important that the research needs be approached in a scientifically sound manner that will result in a thorough understanding of the physical processes involved. In order to identify a program to adequately address these questions within this context, it is useful to organize the research needs into three activity areas:

1. Energy Scene Interaction Phenomena.
2. Algorithm Development: Soil Moisture Estimation.
3. Algorithm Verification/Refinement and Spatial Averaging.

Each of these activity areas will require numerous specific research programs.

Basic Energy Interaction - It is this activity area within which the basic understanding of the physics of the measurements is addressed and the relation of the measurement to the parameter of interest is defined. This activity area will require both laboratory and controlled field experiments involving teams of microwave specialists, soil scientists and hydrologists. Specific points which should be addressed are:

1. Soil permittivity effects.
   a. effect of soil texture.
   b. relationship of permittivity to soil water tension or volume of water under a variety of soil metric constituents.
   c. dependence of permittivity on microwave frequency.
2. Definition of the soil water parameter to be estimated.
   a. depth of penetration.
   b. soil moisture profile to the depth of penetration.
3. Effect of vegetation
   a. penetration capability (as function of biomass, geometry, type).
   b. backscatter component from vegetation.
4. Effect of surface roughness.
   a. periodic (row) structures.
   b. uniform roughness.
5. Development of soil moisture profile/budget model.
   a. design to accept estimated moisture parameter as input.
6. Development of runoff models.
   a. design to accept estimated moisture parameter as input.

Algorithm Development: Soil Moisture Estimation - With an adequate understanding of the physics of the measurement process and a sound relationship between the measurement and a useful moisture parameter, it will be possible to design an algorithm to operate on the measurements and estimate the moisture parameter. This algorithm must be capable of estimating a moisture parameter that addresses the interaction needs of the user community (i.e., the user community must understand how to apply the estimate to their problems). The major components of this activity area are:

1. Algorithm definition.
   a. mathematical representation of electromagnetic energy/soil moisture response (parameterized on scene confusion parameters; vegetation,roughness, scene geometry, etc).
   b. model of soil water profile that accepts microwave and other expected measurements as input.
   c. identification of how to implement these descriptions into an algorithm capable of accurately estimating moisture to the depths required.
2. Approach to algorithm application.
   a. plan of how to apply algorithm over extended scenes (fields).
   b. prediction (or simulation) of algorithm performance for typical scene makeup and topographies.
   c. definition of required ancillary data to achieve adequate estimation accuracy.
3. Verification with controlled ground measurements (point estimates).
   a. demonstration of microwave algorithm baseline performance over well-defined conditions, i.e., near surface estimate.
   b. demonstration of complete soil parameter estimation system i.e., estimate of moisture parameter versus depth utilizing soil water profile/budget algorithm.
   c. determination of incremental performance improvement with passive microwave, thermal infrared.

Algorithm Verification/Refinement and Spatial Averaging - It is necessary to verify the estimation system and plan of application for extended scenes similar to those that are expected during operational utilization of such a system. Aircraft platforms are required in order to acquire such data. This activity area will involve performance testing over a range of surface and climatological conditions and it is expected that the approach to applying the algorithm system, and the system itself will evolve through a refinement process in order to meet accepted limits of performance. At least, the performance (accuracy and precision of the estimate) of the estimation system will be addressed. Major issues of this activity area are:

1. Effect of application of estimation system to an extended scene estimate.
   a. field by field, as opposed to extended scene averages.
   b. determination of effect of scene heterogeneities on average estimate over extended scene.
2. Interpretation and determination of utility of average moisture parameter estimates over an extended scene.
   a. determination of size of area over which average estimate is meaningful.
   b. determination of scene makeup and topography on the interpretation of the average moisure over the scene.
3. Performance of estimation system in reducing effects of confusion factors (vegetation, roughness, topography, etc).
   a. refinement of estimation system to improve performance.
   b. determination of requirement for temporal measurements, i.e., repeat cycle required, and potential for reducing roughness effects.
   c. improvement in performance with passive microwave and/or thermal infrared sensors.
4. Final estimation system definition.
   a. system refinement to optimize performance.
   b. method of application.

TASKS

TASK 1: Permittivity Dependence on Soil Water/Soil Water Tension

The objective is to determine the dependence of soil permittivity on frequency, soil texture, soil constituents

(salinity, clay type) and soil water state (frozen/unfrozen, soil water potential energy). The approach to meeting this objective is to perform controlled laboratory investigations of the relationship to permittivity and soil water as function of frequency from UHF to K-band frequencies. It is expected that this task will provide conclusive evidence that the permittivity of soil is a function of soil water potential independent of soil texture, and quantification of soil permittivity as a function of moisture content and water potential useful in the electromagnetic modeling activities described in Task 2.

Specific elements of this task are:

1. Assemble laboratory facilities for executing permittivity measurements.
2. Assemble laboratory facilities for measuring soil moisture-soil water potential relationships.
3. Implement a measurement program that addresses microwave frequency (at least at each radioastronomy band from 400 MHz through 18 GHz), soil texture, clay type (at least two, expanding and non-expanding types), salinity, frozen/unfrozen.
4. Implement a measurement program to determine the soil moisture-soil water potential for the soil samples used in 3 above.
5. Analyze the measurements to demonstrate the relationship between permittivity and soil water potential as a function of frequency (for at least non-saline soils, unfrozen).

Permittivity measurements at various microwave frequencies are scattered throughout the literature for different soil textures, types and soil water state. However, it is not possible to pull together a consistent set of measurements made for similar soil textures and types and soil water states at all frequencies of concern from these data. In addition, there is no information in the literature that provides the information needed to make a conclusive statement concerning the relationship of soil permittivity to soil water potential. A thorough knowledge of the relationship between soil permittivity and soil water is the basic foundation for the development of models that describe the interaction of electromagnetic energy with soil volumes.

TASK 2: Modeling of Electromagnetic Energy Scattering and Emission

The objective is to devise and/or apply current theories of electromagnetic propagation, scattering and emission to the energy interaction of microwave radiation to soil and vegetation volumes. This will be done by identifying techniques of handling electromagnetic propagation through and scattering from soil and vegetation (both surface and volume) applicable to the soil/vegetation scenes peculiar to the agriculture and hydrologic soil moisture problem.

These tools will be utilized to develop an understanding of the physical significance of the vegetation, soil surface, and soil volume scatter, and use that understanding to develop a physically meaningful soil moisture parameter and identify the soil volume over which that parameter is applicable. They will provide an understanding of the effects of frequency, polarization and viewing angle, and scene composition and geometry on the measurement.

Specific elements of this task are:

1. Identify appropriate models for both the scattering and emission problem.
2. Utilize models to address the definition of physically meaningful soil water parameter.
3. Utilize models to determine soil volume over which soil water parameter is applicable.
4. Investigate the sensitivity of the depolarized energy to the soil moisture parameter and surface roughness effects.
5. Investigate the effect of vegetation on the emitted and scattered energy with consideration given to biomass and geometry.
6. Develop an understanding of periodic surface structure on emission and scattering as a function of incident and azimuth angle.
7. Verify all modeling aspects with controlled field experimental data acquired with truck systems.

The interpretation of a microwave emission or scattering measurement is so complex and dependent on so many uncontrollable scene parameters, that it cannot be empirically related to scene parameters in general. A meaningful understanding of why and how electromagnetic energy interacts with the scene is required in order to identify the soil moisture parameter of importance and identify the soil volume for which that parameter is applicable. Only through analytical/theortical models of this phenomena can a general understanding of the measurement/scene coupling and effects of sensor configuration be obtained.

TASK 3: Development of Water/Temperature/Radiation Soil Profile Models Including at Least One User Model

The objective is to develop soil profile models which utilize remote sensor data as one input. The complex interaction of soil, water, vegetation, and radiation must be modeled using an approach which can accept remote sensing inputs. Two basic approaches including soil profile moisture models and water budget models should be pursued to cover the diversity of field/vegetation conditions encountered. These models should have as inputs: reflective through microwave spectral information, as well as necessary physical parameters.

Presently, many models exist for simulating the soil/water/plant interactions; however, remote sensor data are not included as inputs. Further model refinement and testing must occur. Unless soil depth of influence is understood and can be quantified through modeling, the use of remote sensor derived information will be limited. A method to utilize multifrequency data for assessing moisture gradients is necessary. In agriculture, the moisture profile to the rooting depth of crops is necessary information to assess anything related to water availability to plants.

TASK 4: Controlled Field Experiments

The objective of this task is to acquire active microwave, passive microwave and thermal infrared measurements over controlled and well-instrumented test fields for a diversity of soil, vegetation, roughness, climatological, and soil moisture conditions. The general approach is to use mobile truck mounted systems, and to develop controlled and well-instrumented test fields at appropriate locations around the U.S. These fields must be instrumented to acquire all soils, vegetation, environmental, moisture profile, temperature profile data needed to verify both electromagnetic scattering and emission models and soil profile/budget models. The task will result in an accurate multifrequency, multiparameter data set over all significant scene configurations useful in verifying the models generated in Tasks 2 and 3; the algorithm developed in Task 6, and data required to support empirical analysis.

Active and passive microwave ground-based measurements have been acquired from only one system each. These data are not sufficient to fully address the basic understanding of the electromagnetic energy.

TASK 5: Development and Testing of Spatial Terrain/Moisture Models

The objective of this task is to develop and test spatial terrain/moisture models based upon extension of individual moisture profile models. Models to extend site-specific verified profile models will be prepared. Variations in surface morphology, land cover, soil and other factors affecting radar return will be considered.

There is currently little knowledge of how to apply soil water profile models to areas larger than a few acres. In addition, the interpretation and usefulness of "average" moisture conditions over larger areas is unknown.

This task will provide models appropriate to describe spatial conditions over a variety of landscape differences. This will include an analysis of spatial resolution requirements on measurements for specific applications. Mixtures of scene elements, e.g., vegetation, cultural features, will be simulated to estimate their influence on radar measurements.

TASK 6: Algorithm Development for Soil Moisture Estimation

The objective of this task is to develop and verify an algorithm to estimate soil moisture parameters using remotely sensed data and required ancillary data. The approach suggested is to determine an algorithm that can be used to estimate a soil moisture parameter based on a combination of microwave and soil profile/budget models (at least for the root zone moisture); to develop an approach to applying that algorithm to extended scenes; and to test and verify the algorithm using experimental measurements acquired at controlled test sites to determine baseline performance.

An algorithm that can operate on microwave/thermal measurements to estimate the near surface soil moisture parameter, and that can use that estimate in combination with ancillary data to extract moisture at the root zone depth, should be obtained as a result of this effort. The expected accuracy and precision should be found, and the required measurement repeat cycle, at least for a point estimate, will be defined.

TASK 7: Algorithm Verification/Refinement and Spatial Averaging

The objectives of this task are to determine the performance of an estimation algorithm over an extended scene, to define the utility of such an average estimate, and to finalize the estimation algorithm. The approach required includes aircraft experiments over test sites in at least three climatic regions (arid, semi-aird, humid), each containing a reasonable mix of scene constituents. These measurements should be used to test appropriate algorithms and the results should be compared to one another and to ground-truth data. The task should result in a refined version of the soil moisture parameter estimator, the best approach to applying it to an extended target, and its expected performance from a space platform.

The basic philosophy of approaching the development of a remote soil moisture estimation system is to start with a basic understanding at the electromagnetic energy interaction phenomena, then build on that understanding to develop the moisture parameter to be estimated and an algorithm to do so. The logical progression of development is to first verify the algorithm under as ideal conditions as possible at a point, and determine its baseline performance. After this is understood, it is necessary to extend its applicability to an extended scene. This requires moving to an aircraft or spacecraft platform.

TASK 8: User Data Extraction and Format Needs and Model Development

The tasks outlined above should provide clearly documented microwave sensor capabilities. The objective of this task is to use that information and input from users to design an information extraction and processing system. The recommended approach is to test existing or new user models to use soil moisture information. The user must select system specifications which are necessary for his specific application. System parameters including soil moisture accuracy required, spatial and temporal resolution, data format, timeliness, and necessary hardware and software information extraction techniques will be documented for the purpose of determination of runoff for stream flow forecasting, and improvement of crop yield forecasting. These and/or other critical applications should receive special attention for system design and testing.

The results of this task should provide definition of system design to satisfy user needs. At least two specific applications will be emphasized which are of high national impact, and simulation models should be used to assess the impact of developing a soil moisture monitoring system.

FACILITIES SUPPORT REQUIRED

The tasks proposed in this research area require a significant improvement in the present capability to make microwave measurements at controlled test sites. At least three mobile field measurement systems are required. These should be equipped with a full complement of sensors, including active and passive microwave (3cm to 20cm wavelengths, continuous or multiple discrete), thermal infrared, and multispectral visible instruments. In addition, the existing airborne radar scatterometer systems must be improved to enable them to acquire and, most importantly, process reliable data.

Several of the tasks require fully instrumented test sites. A minimum of three 3-5 acre sites are needed; each in different climate regions. Agricultural maintenance services must be available, and adequate in-situ sensors are needed to record soil, moisture, temperature, and environmental parameters.

EXPECTED RESULTS

This research program is structured to determine the capability of active microwave sensors to record soil moisture content information of value in agricultural and hydrologic applications. It includes tasks to gain a sufficient understanding of the basic electromagnetic interactions involved and to extend this knowledge through the development and application of analytical models. It provides for the tests required to validate the models and, hence, to assess the utility of this sensing technique for soil moisture monitoring.

SNOW

RESEARCH NEEDS

The accumulation of the snowpack in both mountain and flatland areas throughout the winter is an extremely important water resource. In the mountains, this source of runoff generally provides 70% of the total water supply. On the plains, the snowpack is of vital concern because most significant flooding over large areas results during spring snowmelt.

Historically, this snow resource was sampled manually at scattered points throughout the snow accumulation region once or twice per month. More recently, automated methods have become available, and at certain points, continuous monitoring is available, usually in mountain areas. The only improvement over the point sampling technique has been instituted over the northern Great Plains where narrow flight line samples are now flown using low altitude gamma ray techniques to measure snow water equivalent.

It has become apparent that in order to better predict the quantity and timing of snowmelt runoff, it is necessary that snowpack properties be measured over hydrologic units such as sub-basins. Area-wide characterization of the snowpack has not been previously possible and is much needed. Parameters of importance are snow depth and water equivalent, areal coverage, and liquid water content.

Microwave remote sensing measurements of snowpack properties have shown positive results regarding the potential ability to estimate water equivalent and liquid water content. However, the effects of the extremely variable condition of snowpacks on microwave measurements is not well understood. Not only do accumulation and ablation phases change rapidly, but depth, density, grain size, wetness, and internal structure are almost constantly changing. Much has yet to be learned about how variations in snow water equivalent, density, grain size, layering, and wetness affect the response of a particular remote sensor (visible, infrared or microwave).

Specific research requirements that must be met before the potential of active microwave sensors for snow parameters measurements can be assessed are listed below. The majority of these requirements were obtained from the ERSAR Applications Workshop Report.

1. Better understanding of the dielectric properties of snow, especially the imaginary part. (The effect of wetness and crystalline structure have yet to be measured between 8 and 35GHz).
2. Quantification of attenuation and penetration depths for different wetness and crystal size conditions.
3. Quantification of the effect of crystal size variations on radar backscatter.
4. The microwave response to snow water equivalent and depth under widely varying natural conditions needs to be established.
5. The surface roughness effects of wet snow need more detailed study.
6. Fading statistics for both intrafield and interfield variations need investigation.
7. Effect of the state of the underlying soil on radar backscatter for varying snow conditions must be defined.

APPROACH

Active and passive microwave characteristics are generally similar in relation to advantages over visible and thermal IR capabilities in snow studies. They provide an all weather capability; penetration to depth in the pack is possible; and they are extremely sensitve to wetness. An additional advantage of active microwave sensors, over passive microwave sensors, is significantly higher resolution. Most of this is understood. What is not understood is how the radar signal can be interpreted with respect to water equivalent, density, wetness, grain size, and structure, especially under changing snowpack conditions. This research program is defined to determine those capabilities of microwave sensors that are unique to snowpack measurements.

In order to make a statement as to the capability of active microwave sensors for estimating snow parameters, each research need listed above must be addressed in a scientifically sound manner. The approach to addressing these research needs involves the following activities:

1. Development of an understanding of the electrical characteristics of snow at microwave frequencies as a function of snow parameters.
2. Development of a thorough understanding of the electromagnetic energy interaction with snow.
3. Development of an algorithm for estimating snow depth and liquid water content of snow from microwave measurements.
4. Establish an approach to applying this algorithm to area extensive scenes.
5. Establish the unique/complementary capabilities of microwave sensors as compared to visible/infrared sensors.

The implementation of this approach will require a combined effort including laboratory investigations, and field investigations involving detailed ground-truth, ground-based, aircraft, and spacecraft sensors, and modeling tasks. Modeling of the microwave response to snow will drive the collection of field data; whether it be conventional ground measurements, truck mounted data acquisition, aircraft, or spacecraft. Existing microwave capabilities will be employed to the fullest possible extent, and the need for development of new or improved systems will be identified.

In addition, multispectral observations are advocated; both active and passive sensors would be supplemented with visible and thermal infrared instruments. In order to improve the understanding of the complex interrelationships that affect the magnitude and intensity of the backscattered radar signal, the emitted thermal and microwave radiation, and the reflected visible radiation from the snowpack, the initial effort should be concentrated on ground-based sensors and modeling. Aircraft flights should supplement these measurements early in the period and should become most important as understanding increases.

TASKS

TASK 1: Laboratory Investigations of the Electrical Properties of Snow

The purpose of this task is to characterize the electrical characteristics of snow as a function of snow parameters. This will be accomplished by establishing a laboratory facility for measuring the permittivity of snow as a function of microwave frequency, snow liquid water content, grain size distribution, density, temperature, and structure. The microwave response to snow is driven primarily by the electrical characteristics of the snow. The snow information obtained from microwave measurements is only available through an understanding of how the electrical properties of snow vary with the snow parameters of interest.

It is expected that the laboratory facility would be maintained throughout the program. However, the peak level of effort and funding for this task should occur early in the program. It is estimated that during the peak level of effort this task will require 2 man-years of effort per year.

TASK 2: Modeling of Electromagnetic Energy Interaction with Snow

The objective of this task is to develop a thorough understanding and analytical description of the scattering of electromagnetic energy at microwave frequencies from snow. This objective will be approached by applying known scattering models to snow scenes, modifying current models, or developing new models to describe the interaction. Since it is impossible to measure the microwave backscatter from snow for all conditions that could be expected over a watershed, it is necessary to be able to analytically understand and describe the microwave response to snow as a function of snow parameters and scene characteristics. Utilizing this understanding, it should be possible to predict the sensor response for snow and scene conditions not previously measurable in a controlled environment. It is expected that such a model would assist in predicting the effect of soil state (frozen/unfrozen, wet/dry), snow depth, snow roughness, and snow wetness on the microwave response to snowpacks.

Model development and validation will proceed from early in the program to the end. Validation will take place using the multi-level platform data sets collected in the snow study areas. Progress in the modeling task will be used to specifically direct the actual design of the field data collection. Eventually the models will be used as the basis for estimating snow water equivalent and liquid water content.

This activity will require a level of effort on the order of 5 man-years per year.

TASK 3: Development of Algorithms to Estimate Snowpack Characteristics from Microwave Measurements

The objective is to develop a set of algorithms which will

operate on microwave measurements to estimate snow depth, snow liquid water content, and underlying soil state. The algorithms will be developed utilizing the understanding obtained through the modeling efforts described in Task 2. In effect, these algorithms will be techniques of inverting the analytical models to useful snowpack characteristics. These algorithms must be developed in order to provide a basis upon which a strategy for measuring snowpack properties over a watershed can be based. They should be verified using controlled point measurements. Techniques of applying these algorithms to area extensive measurements must also be developed. And, the effect of scene characteristics on the performance of these algorithms when applied to area extensive snowpacks, must be evaluated. This evaluation will require aircraft and/or spacecraft measurement programs.

This task will require approximately 7 man-years of effort per year.

TASK 4: Experimental Verification

The objectives of this task are to: (1) conduct a controlled experimental measurements program to verify the electromagnetic modeling task and the algorithms developed under Task 3, and (2) to conduct aircraft measurement programs to verify and/or assist in developing the approach to applying the algorithms developed in Task 3 to area extensive scenes. The approach to this task is to conduct a phased program of truck-mounted, aircraft, and spacecraft multispectral data collection of a variety of snowpack study areas supported with extensive ground-truth.

A variety of important snowpack study sites will be selected to cover varying snow conditions, as well as varied geographic regions. Specific sites will be selected in the Colorado Rockies, the California Sierra Nevadas, the Pacific Northwest, the Great Plains, and New England. These study sites will provide the capability for allowing a detailed understanding of snowpack processes; accessibility to and mobility of truck-mounted remote sensing packages; and areas large enough to accommodate aircraft flight lines. Some expanded areas will eventually be selected for spacecraft experiments.

Ground-truth data collection methods will be standardized to facilitate ready comparison of data collected in different study sites. A manual of suggested ground-truth methods will be developed for use by all investigators. Detailed ground-truth will be taken in coordination with all remote sensing measurements.

Truck-mounted systems with active radar, passive microwave, thermal infrared, and visible sensors will be developed for deployment at the various study sites for extended data collection periods. Several of these sensor packages will be designed to be compatible with helicopter mounting so that they may be flown over larger areas of the study sites.

Aircraft sensor configurations will be modified to include the various remote sensors recommended above and specified flight lines will be flown respectively in coordination with the ground-based experiments. These flights will be used as the transition from truck measurements to a spaceborne capability.

Only existing spaceborne data will be examined over existing study sites. Information content of the existing data will be examined for continuity with the more detailed ground-based and aircraft data, and to get an idea of eventual spaceborne capabilities. Based on results from modeling, ground-based, and aircraft tasks, a spaceborne configuration will be recommended.

This task will be ongoing for at least a five-year period. It will be an extensive test in terms of both manpower and facilities required. Specific manpower estimates to accomplish this task will depend on the specific objectives and number of experiments required to complete the task. An additional level of detail in program planning is required before this estimate can be made.

TASK 5: Determination of Unique/Complementary Aspects of Active Microwave Sensors of Snow Relative to Other Sensor Systems

The objective of this task is to determine the relative information content of the active, passive, thermal, and visible data for estimating snow water equivalent and liquid water content. The approach is to analyze the data collected in Task 4 by the active and passive microwave, thermal, and visible sensors in terms of snow water equivalent and liquid water content.

Existing data have indicated great promise for using active and passive microwave data for snowpack characterization, with a supplemental role for thermal and visible data. Beyond this, very little quantitative information is available to specify the "best" sensor or the optimum set of sensors. As a result, an integrated experiment is proposed where several sensors are used to collect data on the same set of snow conditions so that the different information contents will be apparent. As a result, it should be possible to specify the proper active microwave wavelengths to be used for snowpack remote sensing, as well as the relative importance of the active microwave compared to the other information sources. Such an approach will maximize the information quantity and quality and minimize the cost of the program.

FACILITIES SUPPORT REQUIRED

To support Task 1, a laboratory facility will have to be developed capable of making permittivity measurements of snow over a wide range of microwave frequencies. This is a unique measurement problem, which will require that special techniques be developed.

To augment the present limited experimental data base, field measurement programs have to be mounted in various important snowpack areas with varying snow conditions. Existing microwave truck systems have to be upgraded to include both active and passive microwave sensors (at a variety of frequencies, 1-94 GHz), plus the supplemental thermal and visible sensors. The field experiments should be designed to allow the trucks to be mobile and acquire data at several different sites throughout the winter. Specific sensor requirements are:

1. Truck-Mounted Systems - five separate systems are required with similar instrument packages facilitating intercomparison. Several instrument packages should be interchangeable for helicopter or aircraft mounting.
2. Aircraft Systems - one helicopter should be available to fly the sensor packages between study areas. The C-130 aircraft should be used to fly flight lines in each of the study areas with comparable active and passive microwave instrumentation.
3. Ground-Truth Facility - five instrumented vans with small cold chambers should be outfitted for use in each of the study areas.

EXPECTED RESULTS

The program should result in a theoretically supported understanding of the microwave response to snow as a function of snow depth, snow liquid water content, surface roughness, and underlying soil state. A technique of estimating these parameters from microwave measurements will be developed and their performance, when applied to point measurements, will be known. In addition, the capabilities and relative importance of microwave sensors for acquiring snowpack hydrologic properties will be known relative to other remote sensing techniques.

It should be noted that this program plan will not result in a technique of estimating snow properties over a watershed utilizing a spaceborne radar system. That will require additional effort. However, it will provide the understanding and knowledge to decide if the development of the application of measuring hydrologic snowpack characteristics should involve orbital active microwave devices.

SEA, LAKE, AND RIVER ICE

Even though floating ice covers roughly 13% of the surface of the World Ocean, less is known about such drifting ice masses than any other major element of the earth's surface. This ice is shrouded in darkness during the winter and by clouds during the majority of the summer. Field operations are invariably difficult and commonly hazardous. Remote sensing, and in particular active microwave remote sensing, provides a way to approach many of the scientific and operational problems caused by the existence of these ice covers. There are two general types of problems that are of particular interest: the problem of such ice masses in the climate system, and the problem of ice as an environmental hazard and as an impediment to marine transportation and offshore development.

The climatic importance of ice is caused by its acting as a barrier to heat flow between the ocean and the atmosphere in the polar regions. The amount of heat transferred is a complex function of the dynamic behavior of the pack as leads open and close and ice thicknesses change. It is also known that storm tracks tend to steer along the ice edge, although the nature of the causes and effects still remain obscure. These same ice motions and the resulting variations in ice thicknesses cause the difficulty of transiting through the ice fields to vary on time scales of hours to days. The large ice masses that form are formidable and a knowledge of their characteristics and frequency of occurrence is essential to safe operations and adequate engineering design for offshore activities at a number of areas of the broad continental shelves of the Arctic.

The Arctic is being rapidly developed and as this development proceeds, it becomes increasingly important to be able to observe in near real time the state of the ice covers. It is also essential to develop the use of ice models to a degree where confident forecasts can be made of the state of such ice masses from hours to centuries in the future. Although ice covers and their attendant problems are present in the polar regions as perennial features, in the Northern hemisphere they extend far south into more populated regions during the winter as sea ice forms in the Gulf of St. Lawrence, lake ice blocks the Great Lakes, and ice jams terminate barge traffic on the nation's inland waterways.

The reasons for the interest of the sea, lake, and river ice community in active microwave remote sensing techniques are simple. Foremost among them is that active microwave systems are not limited by either weather or lighting conditions. Also, such systems allow clear distinctions to be made between first-year and multi-year ice. In addition, SAR imagery is commonly presented in a map format which greatly facilitates its use in a wide variety of problems. Also, the primary ice characteristic sensed by active microwave sensors is the surface roughness of the ice. This is an important parameter that allows the user to gain quite different insights than can easily be studied through the use of visible/infrared or passive microwave imagery. Finally, SAR systems are, in principle, capable of resolutions of a few meters. High resolution is needed to obtain ice velocities with adequate resolution. It is also imperative that spatial resolution be adequate to define the quite small objects of interest. For instance, studies carried out by the AIDJEX program showed that the most common leads in the Beaufort Sea were only 50m wide. Also ridges, which are perhaps the most important ice roughness elements sensed by active microwave systems, are usually less than 10m in width.

In many of the subjects discussed in this report, research is necessary to determine if an active microwave system, in particular, SAR, is capable of determining the parameters of interest. In SAR images of floating ice masses, there are of course, many things that are seen that are not understood. The proposed research should greatly expand the capability to interpret and use this information. However, extensive experience with aircraft SAR and Seasat SAR imagery has shown that spaceborne SAR systems, even when not specifically designed for ice studies, are capable of providing the investigator interested in ice problems with large quantities of important information; for instance, detailed ice motions, lead patterns, floe size distributions, pressure ridge patterns, ice edge locations, and the locations of major ice hazards such as floebergs, ice islands and icebergs. The needs are for designing rapid and efficient ways of obtaining the information of interest from the imagery and for expanding current ice models to incorporate and obtain maximum benefit from such data.

RESEARCH NEEDS

SAR imagery provides information on a wide variety of parameters of interest for the study of floating ice problems. To be specific, numerous distinctive high return targets can commonly be identified in sequential images of sea, lake, and river ice covers, and the relative movements of these targets will give ice strain at innumerable points on almost any scale desired. Also areas of strong return allow identification of pressure ridges and rubble fields. In most cases the position of the ice edge can be clearly defined. Lead patterns and their changes with time are readily apparent. Also, major ice hazards such as floebergs, ice islands, and icebergs have characteristic signatures that allow them to be identified and tracked.

Because the characteristics of drifting ice change rapidly, and correlations between ice masses can extend over large distances (on the order of 1000 kilometers), sea ice studies are quite different from more "static" subjects such as geology in that they require near real time data over large areas with revisit times in the order of a few days for the results to be useful in more than a hindcast mode.

What is needed is fast, routine, automatic to semi-automatic methods for identifying suitable traceable targets and determining their relative motions in map-correct coordinated systems so that the velocity, the strain and the strain-rate fields be determined. These techniques are not available at present. A related problem is the development of the capability to use pattern recognition techniques to determine a wide variety of the parameters such as the areal percent of deformed ice, open water, multi-year ice, lead orientations and spacings, floe size distributions and roundness, and the presence of particular ice hazards.

These target identification and data analysis problems must be faced if SAR imagery is ever to be fully utilized. The solution of these problems will require the development of procedures and software by a working team composed of sea ice and pattern recognition specialists. It will clearly require several years of effort. Methods must be developed to incorporate information obtained from remotely sensed data into current ice models. This is far from a trivial problem in that interfacing will be difficult. At present, there is no model available that is designed to accept the data that could be produced by a spaceborne SAR system. A number of questions present themselves. What data are needed and how frequently? Will the data be used incrementally to recalibrate the model? What are the optimum space and time scales for the different information? What are the effects of errors in the different SAR determined parameters on uncertainties in model outputs?

In the ice operations area, there is a need to develop systems for real time transmission of SAR imagery to users at isolated locations such as ships and off-shore drilling platforms. There is also a need to develop guides for the interpretation of SAR images that are meaningful to different classes of users.

There are many aspects of the active microwave characteristics of floating ice masses that are poorly understood. For instance, little quantitative work has been undertaken on the backscatter coefficient of different sea ice types and the physical basis for these variations. The problems of the effect of volume scattering and of variations in the effective skin depth in multi-year ice has

received some attention, but additional work is needed. Surface roughness is clearly the most important parameter in determining the backscatter coefficient of many sea ice types, yet no quantitative analysis has been done. At some times the snow cover on the surface of sea and lake ice appears transparent; at other times the snow gives a strong return that can mask ice characteristics and produce ambiguities in image interpretation. There has been no quantitative examination of the processes involved. Another problem is that the radar return of areas of deformed ice is highly variable as the radar azimuth changes. This causes difficulties in the determination of identical locations on repeat images in studies of ice movement. Detailed studies relating the nature of the radar return from piles of broken ice to the block structure of the piles could be most useful here.

These problems can only be resolved by combined laboratory studies, theoretical analyses, and field studies. In the field studies, it is important to utilize surface-based sensors that are capable of in situ measurements on small, well defined ice areas. This work must then be combined with detailed characterizations of the properties of the ice under study. Parameters of interest would include ice temperatures, salinities and brine volumes, crystal orientations, grain sizes, snow properties, and gross surface roughnesses. In lake and river ice areas, it may also be necessary to determine the physical roughness of the ice-water interface as this can be a quite important factor because of the near-transparency of fresh water ice at radar frequencies.

Such studies are time consuming and costly, but if they are not undertaken the understanding of the active microwave signatures of ice covers will remain at a qualitative level. This situation will limit future developments in the application of SAR and other active microwave systems to ice problems.

Documents such as this invariably focus on the capabilities of a specific remote sensing technique. In fact it is now well documented that most ice related remote sensing problems profit from the joint utilization of two or more remote sensing techniques. It would be very useful to expand the parameter study performed for the ICEX Experiment to examine the optimum combination of sensors required to determine a variety of different aspects of floating ice covers. For instance, if a combination of active and passive microwave systems are used, both the dynamics and the thermodynamics of ice processes can be examined. Particular attention should be paid to data formatting so that intercomparisons between data sets are facilitated. This process will have to be continuously updated as new instruments and techniques are developed.

Radar altimetry may be of great use in studies of the roughness characteristics of ice covers in that it measures the mean height of the ice, its roughness and the total mean surface slope. There is reason to believe that it may be possible to make quantitative estimates of the power spectrum of the ice surface and the ridge height distribution from the nature of the radar returns. To work out these relations, additional measurements are necessary on the nature of the radar return from well defined rough surfaces. Also needed are further theoretical investigations of scattering from different types of surfaces. Such work could also be of use in estimating underwater sound attenuation caused by scattering off pressure ridge keels and in providing estimates of the aerodynamic surface drag coefficient of the upper ice surface and the hydrodynamic drag coefficient of the ice-water interface.

Scatterometry provides an important addition to SAR imagery in that it allows the direct determination of water-ice boundaries, the discrimination between multi-year and first year ice and information on the surface roughness of the ice. It is quite possible that correlations can be developed between the nature of the scatterometer return and the distribution of roughness elements on the upper ice surface. Scatterometry also permits ice type differentiation in both lake and river ice, although insufficient work has been performed on this subject.

APPROACH

The approach recommended to satisfy the stated research needs involves three interrelated field programs. These tasks are intended to clarify the microwave properties of ice in a variety of different geophysical situations where different processes are at work. The tasks examine important aspects of the ice component of climate, oceanography, and polar ice operations related to shipping and off-shore mineral exploration.

The three research tasks provide data sets for velocity calculation research in areas of feasibility and data product automation (pattern recognition and processing); provide ground-truth for interpretation of microwave intensity and structure; and provide input and verification for models. These problems have been discussed in the proposed ICEX literature (Ice and Climate Experiment, Report of Science and Applications Working Group, Goddard Space Flight Center, December 1979). Also proposed is a study to update the design of optimum sensors for geographical studies of ice. In fact, the total scientific program is much enhanced when SAR data are supplemented by select passive radiometers, and possibly enhanced by the addition of scatterometry and altimetry.

The assessment of priorities to the recommended field programs hinges on unique opportunity and absolute need. The ice edge experiment (Task 1) and the summer ice experiment (Task 3) could be done using an orbital SAR sensor. However, the basic problem of proving the feasibility and establishing the automated or semi-automated methods of ice velocity, strain and strain-rate calculation, can only be performed if the winter-pack experiment (Task 2) is carried out. There is still a pressing need for ice edge work and summer ice studies. If the programs were carried out prior to SAR launch, the scientific community would have a quality pilot program data set in hand and would have a head start on the required modeling effort. Also, the definition of optimum instrument aggregates for space deployment is a necessary ongoing task as the state-of-knowledge increases. Specific funding for this task could await a decision of SAR deployment.

The deployment of SAR prepared for by appropriate surface and process studies, would be an immense boon to sea ice science: important information on the state of sea ice in climate, oceanography and meteorology, and operations such as hydrocarbon extraction and shipping. Knowledge of ice velocity fields of the polar oceans would lend to important conclusions of the pathways of heat in the poleward heat transport.

Field studies are recommended as valuable geophysical experiments and necessary preparatory work to an effective SAR mission. In addition, work should proceed on timely deployment of an optimum spaceborne SAR. Sea ice studies call for an instrument with a wide swath and with a high revisit frequency in a polar orbit; look angle and frequency are less significant issues, although X-Band at about 45° look angle appears optimum (ICEX SAWG document). Processing capabilities must be adequate for near real time product delivery. Even without any preparatory studies, the information garnered by such a deployment would result in a major advance in the understanding of both the geophysics and operational problems of floating ice covers.

TASK 1: Ice Edge Experiment

The objective of this task is to determine the microwave properties and geophysical processes of the ice pack near the boundary of the ice and the open ocean. Processes at the ice edge play a large but unanalyzed role in determining the extent of ice and, therefore, the global albedo, and in controlling the oceanic and atmospheric poleward flux of

latent heat. The ice at the edge undergoes processes not present in the center of the ice pack; temperatures and precipitation are higher, oceanic swell is large and ice floes are correspondingly smaller, oceanic heat and salt content variations are much larger, meteorological processes are stronger and solar radiation plays a more important role. The processes also alter the microwave character of the ice, and decrease the utility of the more easily obtained information from the central pack. Thus, a research effort is required to determine the influences of the environmental factors on the ice, and to understand both the dynamics and the problems of surveillance of the ice edge. In general, there are two kinds of ice edges to be considered: one typified by the Bering Sea which exhibits similar conditions to much of the ice edge in the southern ocean; the other typified by the East Greenland drift stream which appears to be similar to the Weddell Sea ice edge. Studies are proposed for both cases. Two field programs should be conducted, one in the Bering and one in the East Greenland Sea. The technical objectives are to measure from ground-based systems, the microwave character of the ice species found near the ice edge. Ships can be used for acquiring data at the extreme edge where helicopters cannot operate, and at the same time they can be used to collect information on oceanic heat transports and fronts. Surface parties should measure parameters such as ice thickness, salinity, snow character, temperature, and floe size. Aircraft missions can obtain photographs showing ice pack character such as floe size and lead geometry, and record active and passive microwave sensor data on the ice aggregate present. An associated buoy program can contribute information on meteorological forcing and oceanic structure. The utilization of a model of the ice edge including appropriate ice pack parameterizations, atmospheric forcing, and oceanic current and frontal structure, should be included as part of the experiment. Studies of model sensitivity, sources of error, and ways to effectively incorporate remote sensing data into such models would by highly useful.

This task will require approximately 10 man-years over a five year period, plus data acquisition costs.

TASK 2: Winter Pack Experiment

The objectives of this task are to determine the microwave properites of the central ice pack on a variety of scales, and to demonstrate high precision velocity field calculations and ice hazard identification.

The task includes the measurement of the ice velocity field on 2-3 day time scales as a top priority, thus producing an important data set for future work. Also, the direct measurement of the products of ice deformation is planned. Simultaneous measurement of microwave data and ice properties will serve to confirm ice type identifications. Measured deformations can be compared with modeled lead and ridge production. The issue of pattern change with azimuth or, equivalently, time, can be addressed with a high quality data set. Data for this experiment will be principally taken by aircraft. Ground-truth studies are less important because more is known about central pack ice.

The dynamics of the ice pack remain the most significant research problem in polar science. The past programs have served to establish that the scales of motion which control the critical deformations of the ice are quite small—less than 40 km in length. Thus, for ice velocities of 5-10 cm/sec., ice floe locations must be determined on 2-3 day intervals or the critical translation events will be blurred. The bulk properties of the ice pack depend principally upon ice dynamics, and these properties control the seasonal cycle of ice extent, the latent heat export, the frequency of occurrence of navigational hazards, and other significant features. This task addresses the fundamentals of ice dynamics, and the observational program includes all the elements of ice deformation: driving terms, pressure ridges, leads, and the basic velocity field.

This task will require an 8-10 man-year effort, plus data acquisition support.

TASK 3: Summer Ice Experiment

The objective of this task is to determine the influence of summer ice and ice ridge characteristics on microwave sensor measurements.

Summer ice of the Arctic remains the least understood ice species due to the operational difficulties of performing studies during this season. Microwave and visible sensor data on the properties of typical summer floes, which may contain both fresh and saline melt ponds of varying size and total fractional area, must be determined. A critical climatological question concerns the total extent of summer pack and the processes which control it. The heavy stratus cloud layer which blankets the Arctic in summer makes microwave studies uniquely applicable to this problem. Synthetic aperture radar is essential to resolving the dynamics of the ice motion in this season. To understand the data from the ice and to be confident of the exact ice features which provide the recognition elements, a detailed aircraft and surface properties program is necessary.

A field program in the central Arctic is recommended for this task. The technical objectives are the measurement of the surface microwave and physical-chemical properties of the ice species including ice floes, ridges, melt ponds and, if present,the transition ice in the leads. An aircraft program should produce mosaics of a 50Km x 50Km square for velocity and ice concentration studies on a 3 day interval for a 30 day period. If available, an icebreaker can be employed for logistics. A buoy program can provide meteorological information. Free-drift type ice models can be run and compared to the acquired dynamics data for assessment of parameterization needs and problems.

This task is expected to require 3-5 years of effort over a 5-year period, plus data acquisition support.

These three field programs contain many common elements. All require surface parties to perform microwave, as well as physical-chemical studies of ice species properties. All require extensive aircraft support for the primary data. The ice edge and summer ice experiments would benefit enormously from ship support—the ice edge experiment would probably be unsuccessful without it. This situation calls for inter-agency collaboration. This should not be a problem as these research areas have become pressing to a number of civilian and military tasks. Finally, modeling is a key component in all four research program elements. This reflects the high importance modeling has attained in sea ice work because of the complexity of the problems. Aircraft time to complete all programs will be between 200 and 300 hours.

GLACIERS AND ICE SHEETS

The potential of SAR to contribute to studies of glaciers and ice sheets does not appear to have received much attention. The activity in glacier remote sensing has been largely focused on the use of airborne radio echo sounders (10-60 MHz) to profile the bottom surfaces of such ice masses and also to study patterns revealed by internal reflections within these masses. Another area of activity is the utilization of spaceborne radar altimeters to determine detailed profiles (1m)of the upper surfaces of the larger ice bodies, in particular, those in Greenland and Antarctica.

Although radar data exists of some glacier systems that were imaged as targets of opportunity, systematic studies have not been made to determine the potential applications of this data. A number of possible applications can readily be suggested. For instance, the delineation of morainal material beneath a snow cover, the determination of the firn line, the sensing of structures within glaciers, and the utilization of radar reflectors in the ice flow problems.

Preliminary studies have suggested that the development of a synthetic aperture radar profiler for ice sheet studies is a definite possibility. The development and deployment of

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such an instrument would permit detailed profiling of the bedrock surface beneath ice sheets and the mapping of a variety of internal structures within these ice bodies. Inasmuch as bedrock shapes change extremely slowly, these are essentially one-time measurements. Therefore, such a program could be ideal for deployment via Shuttle.

Analysis of radar altimetry data from Greenland obtained by the GEOS satellite has shown that great improvements in the knowledge of the surface topography of ice sheets are possible using such techniques. Systematic collection and analysis of such data, combined with profiles of the ice-bedrock interface, will finally allow precise estimates of the mass of ice contained in these large ice sheets. Sequential measurements of such data separated by times of a few years, will also give good estimates of the mass balance of the ice sheets. This information is very important in many aspects of the study of climate. In addition, the preliminary studies of the GEOS data have shown surface irregularities that may be kinematic waves, i.e., "rapidly" moving surface expressions of the flow processes within the ice sheet. Also, because radar altimetry obtains information on the roughness of the ice and snow surfaces, it may be possible to map changes in the development of sastrugi fields.

TASK 1: Glacier and Ice Sheet Study

The objective of this task is to assess the utility of SAR data for studies of glaciers and ice sheets. Previously acquired radar image data will be used in this effort.

Much SAR data of the glaciers of Alaska, Scandinavia and Canada have been acquired by NASA and other aircraft. These data have apparently not been studied in detail. Some of the glaciers overflown are subjects of long-term study and remain fruitful sites for the study of ice flow characteristics. Also, icebergs calved from coastal glaciers are significant navigational hazards in the bays of Alaska, Baffin Bay and other waters. Since SAR information would originate from beneath the surface as well as at the surface, it is likely that characteristics related to the nature of the flow of the ice could be discernible in the imagery. A modest data examination effort is justified. A 2 man-year effort is required.

TASK 2: Polar Ice Sheet Soundings

The objective of this task is to determine the bedrock topography of Greenland and Antarctica by deploying a radio echo-sounders device (100-200 MHz frequency) aboard the Space Shuttle.

At present, bedrock topography is being studied by airborne radio echo-sounder in Greenland and Antarctica. This process is quite slow, especially in Antarctica where only a few dedicated flights per year are possible. Also, operations in Antarctica are very expensive and the available research facilities are needed for a diverse variety of programs. The measured bedrock topography is useful for two disciplines: ice sheet dynamics for correct gravitational forcing, and geology for tectonic processes. Also, airborne data from Antarctica shows complex and tantalizing laminar structures within the ice sheet. These structures may tell a great deal about ice sheet strain and flow. This program would shorten the time required to obtain detailed coverage of Greenland and the Antarctic by many years, possibly decades.

Two years (4 man-year effort) are needed for program definition and 3 more years are required to implement and deploy the sensor.

TASK 3: Interpretation and Utilization of Radar Altimetry Data From Ice Sheets

The objectives of this task are to produce improved surface topography of Greenland and the Antarctic, develop automated procedures to facilitate such work, and to explore the potential for the use of radar altimetry to study kinematic waves and the roughness of snow surfaces. The approach is to utilize all pertinent radar altimetry data from the GEOS satellite and from the proposed NOSS satellite to determine the topography and study the waveform characteristics of the surfaces of these ice sheets.

The quality of the topographic maps of Greenland and Antarctica is very poor. In some cases, major topographic features such as large domes have been completely missed. Improved topography of the quality possible by the use of radar altimetry will also finally allow accurate estimates to be made of the mass balance of these ice bodies. In addition, it has never been possible in the past to observe kinematic waves on ice sheets. The study of this phenomena will contribute to a better understanding of ice dynamics.

A large set of data useful to this program already exists. Systematic analysis of this data should be started. Also, procedures should be developed to automate the reduction of this data and to speed its incorporation in a continually updated map and data bank.

TECHNOLOGY

This section begins with a summary of the research needs identified by the agriculture; geology; land cover; and water, ice, and snow panels. From these research needs, specific requirements for technology development activities are enumerated. These technology development needs are then surveyed to identify those radar systems and engineering development activities which are a common denominator to addressing the research needs. The systems already in existence are identified and evaluated against the indicated needs. This information is then used to identify gaps in radar systems and data processing technology, including new truck, helicopter, and aircraft radar systems covering missing frequencies and polarizations, as well as required improvements in existing radar systems and data processing techniques.

The Technology Panel also identified broad categories of engineering development activities which are required in order to meet the research needs identified by the other panels. These hardware and software development activities have differing priorities which are in part determined by the priorities of research needs in the applications areas. Although the Technology Panel did not make judgments on the priority rankings of all the research needs, it foresaw that some of these engineering and systems-related developments are crucial to a broad category of applications areas and should be undertaken as soon as possible. Others have intermediate and long-term recommended development schedules.

The greatest problem facing the active microwave remote sensing community at present is the difficulty in acquiring timely, quantitatively significant, and repeatable measurements of radar return. Therefore, it should be stressed that the greatest immediate need in the technology area is to update, refurbish, calibrate, and improve the reliability of the present truck and aircraft scatterometers, as well as the present aircraft imagers. This priority is underlined by the increased demand for calibrated radar data as reflected in the specific research needs identified by the applications panels. The second greatest priority is to increase the number of fully-instrumented truck scatterometer systems and to make them more mobile and data efficient.

SUMMARY OF RESEARCH NEEDS

In attempting to determine the expected demand for data acquisition and processing systems and facilities resulting from the proposed research program, the Technology Panel reviewed the objectives advanced by each discipline panel. These were analyzed to determine the type and number of sensors and support systems needed. These needs were then compared with the present inventory and any deficiencies were noted. The technology tasks specified

later address these deficiencies.

The research objectives of the discipline panels are, generally:

Geology

1. Provide an extensive SAR data base of land areas, with uniform viewing geometry, resolution equivalent to Landsat D Thematic Mapper, large incident angle, at least 50km swath width, and geometric fidelity sufficient for cartographic and radargrammetric purposes.

2. Determine quantitative relationships between geologic materials and the SAR system parameters, such as (a) measurement of radar backscatter as a function of system parameters and geologic surface variables, (b) quantification of relationships between radar imaging geometry and land surface topography, and (c) correlation of current knowledge of geobotanic relationships with SAR response to vegetation.

3. Determine the extent to which radar imagery can be used for relating texture to surface units and tone to lithologic units, for drainage pattern mapping, and for mapping of correlated (geologic and nongeologic) lineaments and uncorrelated lineaments.

4. Expend concentrated effort in area of education and training for geologists in SAR interpretation.

5. Improve methods for archiving and distributing existing SAR data and develop plans for handling future data.

Agriculture

1. Determine radar response from crop lands in terms of scene radiation characteristics and electrical parameters. Relate radar return parameters to physiological attributes through models.

2. Determine basic radar response from forests in terms of change in forest base, forest stand condition, forest type and extent, and such radar system parameters as wavelength, polarization, incident angle, etc.

3. Determine optimum radar parameters for measurement of soil moisture.

4. Determine basic radar response to rangeland vegetation (acreage, type, biomass, etc.) and identify optimum radar parameters such as wavelength, angle of incidence, polarization, etc.

5. Determine usefulness of aircraft SAR imagery in mapping near surface soil salinity over wide soil moisture range in both North Central Plains and in irrigated agricultural areas.

6. Develop techniques for extension of point measurement of radar return to extended area radar return by identification of optimum cell size parameters, etc.

7. Investigate the utility of image analysis and pattern recognition techniques in relating multi-spectral and multi-temporal imagery from both radar and visible/infrared (VIR) data over extended scenes of crop land, forests, and rangeland to taxonomic units, e.g., crop type or condition attributes, e.g., crop vigor.

8. Investigate data preprocessing required (a) to remove unwanted effects in radar data and (b) to register the radar data so as to be compatible with other radar or VIR data.

Land Cover

1. Establish an active microwave spectrometer data base of urban to rural microwave spectra.

2. Investigate relationship of environmental and temporal factors of land cover to radar system parameters.

3. Improve preprocessing and classification algorithms for use in land cover pattern recognition.

4. Investigate the feasibility of producing radar image data to meet National Map Accuracy Standards for cartographic and planimetric accuracies.

Water, Ice, and Snow

1. Determine the capability of radar sensor data to assist in development of hydrologic models at varying levels of spatial resolution with special emphasis on soil wetness.

2. Establish sensitivity of radar backscatter to snowpack characteristics (especially wetness) and to underlying surface conditions.

3. Document capabilities of radar sensors to measure types, velocities, strains, etc. of floating ice, with special emphasis on marginal ice zones of Arctic ice pack.

REQUIREMENTS FOR TECHNOLOGY DEVELOPMENT

The previous section enumerated specific research needs which were found by the application panels to be essential requirements for answering basic questions on the potential of radar remote sensing. Each panel outlined a plan for addressing each research need, and in many cases they requested radar data sets at a variety of frequencies, polarizations, angles, etc., and from truck, helicopter, aircraft and spacecraft platforms. In some cases, the requested radar data set was derived from previous radar measurements from trucks or aircraft platforms in programs where an optimum set of radar parameters was identified under site or time-specific conditions in the field. Examples of this include radar response from crop lands, moist soils, and snowpacks. In other cases, the request for radar sensor data is based on theoretical models or inference from the results of analogous experiments in other similar research, or from the results of only one experiment. Examples of this include research studies of quantitative relationships between geologic surface variables and radar system parameters. Finally, there are high priority research needs and associated technology requirements associated with such areas as forestry, rangeland, and land cover for which almost no baseline data sets exist at present and for which a broad range of frequencies, angles, etc. are required in order to support the research needs.

In this section, the requirements for acquisition and data processing systems as derived from the relevant research needs . It is important to note that in almost all of the research needs there are requests for timely, calibrated radar data from a variety of platforms and at several frequencies and incident angles. These acquisition and data processing systems requests have been broadly categorized into three elements:

1. Radar sensors required.
2. Calibration and registration required.
3. Data processing and merging required.

This may be viewed as a first-tier organization of technological requirements from the applications community. A second tier translates this into more detailed engineering systems design problems which are beyond the scope of this report. The requirements for sensor systems are summarized in Table 7 and are discussed in the following.

Geology

Provide Extensive Land SAR Data Base - This research need specifies a requirement for a spaceborne SAR, although it does not delineate specific platforms (Shuttle or free-flyers), nor specific optimum frequencies. An incident angle large enough to avoid layover is required and a swath width of at least 50km is needed. Resolution equivalent to Landsat-D Thematic Mapper and geometric fidelity sufficient for cartographic and radargrammetric purposes is needed. There is agreement that an X-band imager would be useful.

Determination of Quantitative Relationships - This is a requirement for a broad category of studies to establish

TABLE 7.

APPLICATIONS REQUIREMENTS FOR TECHNOLOGY DEVELOPMENT

RESEARCH NEEDS	SPACECRAFT IMAGERY	AIRCRAFT IMAGERY	AIRCRAFT SCATTEROMETERS	OTHER A/C DATA	HELICOPTER SCATTEROMETERS	TRUCK SCATTEROMETERS	RADAR CALIBRATION REQUIRED	GEOGRAPHICAL REGISTRATION REQUIRED	DATA MERGING REQUIRED
AGRICULTURE									
1. Radar response from croplands		X-band SAR, VV, HH K_u-band SAR	X-band + K_u-band, high angles	C-130 MSS/VIR	X-band Scatt.	X-band MAS data, 40°-60°, HH, VV	± 1dB	±25m	Digital Merging of C-130 MSS/VIR and X-band SAR images
2. Radar response from forests	-	X-band SAR, VV,HV,HH -------- C-band SAR VV,HV,HH	X-band + C-band 0°-60°, HH,HV,VV	C-130 MSS/VIR	X-band and C-band Scatt.	X-band and C-band HH,HV,VV	±1.8 dB ($\bar{X}$-band) ±1.0 dB ($\bar{C}$-band)	±20 m ($\bar{X}$-band) ±50 m ($\bar{C}$-band)	Man/optical merging of SAR and MSS/VIR data
3. Radar response from soil moisture	-	-	-	-	-	L-band and C-band 5°-20°	-	-	-
4. Radar response from rangeland vegetation	-	C-band and X-band SAR HH,VV	L-band, C-band, X-band, K_u-band HH,VV	C-130 MSS/VIR	-	L-band, C-band, X-band, K_u-band 10°-60° HH & VV	±1 dB	-	Multi-temporal merging of A/C SAR images
5. Radar response from soil salinity	-	L-band, and C-band SAR HH,HV	L-band, C-band, 15°-25°, HH,HV	C-130 MSS/VIR	-	L-band, C-band, 10°-40°, HH,HV	±2dB	±20m (saline seeps) ±100m (irrigated agri.)	Multi-temporal merging of A/C SAR images
6. Image analysis and pattern recognition techniques	Landsat MSS & TM	X-band & K_u-band	-	-	-	-	±2dB	-	Multi-temporal merging of VIR and SAR images.
GEOLOGY									
1. Provide extensive land SAR data base	Large incidence angle, spaceborne SAR	-	-	-	-	-	-	-	-
2. Determine quant. relationship between geologic surface variables and radar system parameters	-	L-band, C-band, X-band SARs, dual-pol.	L-band, C-band, X-band 10°-60°	-	-	1-18GHz JPL Truck MAS	±1 dB relatives ±2.5 dB absolute	-	Merging of multi-frequency and multi-pol. SAR images

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TABLE 7.
(continued)

RESEARCH NEEDS	SPACECRAFT IMAGERY	AIRCRAFT IMAGERY	AIRCRAFT SCATTEROMETERS	OTHER A/C DATA	HELICOPTER SCATTEROMETERS	TRUCK SCATTEROMETERS	RADAR CALIBRATION REQUIRED	GEOGRAPHICAL REGISTRATION REQUIRED	DATA MERGING REQUIRED
3. Determine utility of radar images for relation to surface and lithologic units, drainage pattern mapping, lineament mapping	SEASAT and SIR-A imagery Landsat	L-band and X-band SARs, HH,HV,VV	-	-	-	L-band and X-band 40°-60°, HH,HV,VV	-	-	SAR and Landsat merged data sets
LAND COVER									
1. Establish active microwave spectro. signature bank of urban to rural spectra	-	-	P,L,C, X and Ku bands, 10°-60° dual-pol.	-	1-18GHz, 10°-60°, dual-pol.	-	-	-	-
2. Investigate relation of environmental/temporal land cover factors to radar system parameters	-	L-band, C-band, X-band SAR imagery dual-pol.	P,L,C, X and Ku bands, 10°-60° dual-pol.	C-130 MSS/VIR imagery to coincide with scatt. data	-	-	±1dB relative ±2dB absolute	-	-
3. Improve preprocessing and classification procedures for radar data	-	-	-	-	-	-	±1dB relative	-	-
4. Establish cartographic properties of spaceborne SAR data	SEASAT and SIR-A L-band imagery	-	-	-	-	-	-	Sufficient to meet National Map Accuracy Standards	Digital terrain model compensation to SAR imagery and merged multi-pass SAR images
WATER/ICE/SNOW									
1. Determine usefulness of radar data to assist in development of hydrologic models and estimation of soil wetness.	SEASAT L-band imagery	L-band, C-band, X-band SAR imagery	L-band C-band, X-band dual-pol.	-	-	1-12GHz MAS data, 10°-40° dual-pol.	-	-	-
2. Establish sensitivity of radar backscatter to snowpack conditions	SEASAT, SIR-A L-band imagery	L-band, C-band, X-band, K_u-band SAR imagery	L-band, C-band X-band K_u-band	-	-	1-18GHz MAS data, 10°-50° dual-pol.	±1dB relative for A/C imagery	-	-
3. Document capability of radar sensors to characterize floating ice. (See also results of ICEX parameter study.)	- Radar altimeter, 100-200 MHz needed on shuttle	L-band, X-band SAR imagery dual-pol.	L-band, C-band, X-band K_u-band dual-pol.	-	-	-	-	-	-

specific and quantitative relationships between geologic surface variables and the parameters of a radar system used to sense those surface expressions. This would be investigated through point and extended area radar measurements by the use of truck scatterometers (1-18 GHz), aircraft scatterometers (L, C, and X-band from 10° to 60°), and by L, C, and X-band aircraft imagery with variable resolution adequate to separate different levels of surface roughness. Multiple polarization and a wide range of angles are required. A relative calibration of ± 1 dB, and an absolute calibration of ± 2.5 dB is required for all radar sensors. Multi-frequency SAR images would be merged, and multi-polarization images at the same frequency would be merged. For the study of radar imaging geometry to land surface topography relationships, registration of stereo aircraft Seasat and SIR-A radar imagery to digital terrain data, along with equalization of scale and resolution is required. For the study of radar imaging geometry to geobotanical factors, equalization of scale and resolution for multi-frequency and multi-polarization aircraft imagery is required.

Determination of Usefulness of Radar Imagery - This research element would make use of both Seasat and SIR-A imagery for texture and tone studies, along with additional aircraft X and L-band SAR imagery. Selected ground sites would be spot-checked with high-angle L and X-band truck scatterometer data with the same polarizations (HH, HV, VV). SAR and Landsat data would be merged for studies of topography over heavily canopied areas. Data processing procedures would include registration and equalization of L-band and X-band aircraft SAR imagery.

Agriculture

Determining Radar Response from Crop Lands- Fundamental radar research at the University of Kansas has suggested that optimum radar discrimination among crop types (corn, soybeans, milo and wheat) and sensitivity to crop condition is found in the 10-14 GHz frequency band, for incident angles between 45° and 60°, using VV and HH polarization, at specific sites and times during the growing season. In order to confirm this prediction, independent measurements by truck, helicopter, and airborne scatterometers operated in the X and K-bands and at high incident angles are desired, along with X-band aircraft SAR imagery, VV and HH polarized at 50° angle of incidence. The truck data would be taken weekly at five test farms, and would be complemented by helicopter and aircraft X and K-band scatterometer data at five times during the growing season during two consecutive years. X-band aircraft SAR imagery would also be obtained simultaneously with the aircraft scatterometer overflights. A radar relative calibration of ± 1 dB, and a geographical registration of ± 25m is required. It is envisioned that visible/infrared data from the C-130 aircraft and X-band SAR data from the WB-57 aircraft would be merged. Also, it will be necessary to merge multi-temporal data. Preprocessing procedures are needed which (a) reduce data dependence on look and incident angles, (b) eliminate atmospheric effects, (c) reduce speckle effects, (d) geometrically register imagery with standard projections, (e) eliminate topographically-induced image distortions at the high frequencies, and (f) identify the effect of resampling from the above corrections.

Determining Radar Response from Forests - Although some preliminary qualitative photo-interpretative investigations of radar response from forests have been conducted using X-band radar imagery, no systematic quantitative investigations of optimum radar parameters for forest condition, species and changes have been undertaken. However, because of the similarity between the physics of the interaction between microwave energy and a forest canopy and that of a crop land canopy, there is reason to believe that optimum radar parameters can be identified for both areal extent and condition of the forest canopy. X-band radar data will be used for determination of areal extent, and C-band data will be used for condition determination. Because of the special problems inherent in obtaining baseline data sets from canopies often exceeding 30m height, the prime platforms for scatterometer data would be helicopters and aircraft, both acquiring X-band and C-band data from 0° to 60° incident angle. This research need also would be addressed by the acquisition of X-band and C-band aircraft SAR data taken at five times yearly during two consecutive years. C-band and X-band truck scatterometer data would also be taken for smaller height coniferous forest species, e.g., juniper, etc. A radar relative calibration of ± 1.8 dB is required at X-band and ± 1.0 dB at C-band. A geographical registration of ± 20m is required at X-band with ± 50m at C-band. In addition, there is a requirement for dual polarization capability at both X-band and C-band in order to support the need for relating the polarized radar response to tree canopy structure. It is anticipated that aircraft SAR and C-130 MSS data will be manually (optically) merged.

Determining Optimum Radar Parameters for Measurement of Soil Moisture - An extensive four year investigation relating radar return to soil moisture has been reported by investigators at the University of Kansas, who found using truck-based scatterometers over bare and vegetated fields, that there is a strong correlation between the radar return and soil moisture expressed as a percent of field capacity at C-band for an approximate 15° incident angle, for site and time-specific field conditions. This has not been confirmed by independent measurements. This research element would conduct such an independent investigation, using only truck-mounted scatterometers which would be operated at both L-band and C-band for incident angles between 5° and 70°, and for all polarizations at several sites, over several years. No aircraft data are requested.

Determine Radar Response from Rangeland Vegetation - Some limited qualitative photo-interpretive investigations of rangeland mapping using X-band radar imagery have been conducted, using texture and tone for delineating boundaries, etc. However, no systematic quantitative investigations of radar response to rangeland vegetation have been undertaken and no optimum frequencies, polarizations, or angles have been suggested. The potential of radar for measuring rangeland extent and condition is based on phenological expressions of the water content in the canopy and the sensitivity of the radar backscatter to that water. This would be investigated by the acquisition of a baseline data set at L, C, X, and K-bands over incident angles from 10° to 60° from both truck and aircraft scatterometers, and from C-band and X-band aircraft SAR imagers. Since the water content per unit canopy volume is low (in comparison to crop lands), the essential measurement is the detection of changes in water and, therefore, of backscatter during the green biomass season. Aircraft imagery is requested at two week intervals during two consecutive years of the green biomass season. Aircraft and truck scatterometer data are required at one month intervals during the first green biomass season. Radar sensor relative calibration stability of ± 1 dB over the entire green season is required in order to make multi-temporal signature measurements.

Determining Radar Response to Soil Salinity - A recent investigation by New Mexico State University scientists of the response of aircraft scatterometers to saline seeps in the North Central Plains has shown a large change (about 20 dB) in radar backscatter at L-band, 20° angle of incidence, when comparing saline seeps to non-saline surrounding areas. Although a portion of this is due to increased moisture associated with the seep, much of the measured response is due to the strong effects of soil conductivity seen at lower frequencies. This finding, based solely on aircraft data over

one site in South Dakota and at one time during the year, has been taken as a partial confirmation of the prediction of theoretical models that microwave backscatter should be strongly influenced by soil salinity, particularly at the lower frequencies where the conductivity effect is a strong component in determining the reflection properties of the soil. This research element envisions two geographical areas for confirmation of the soil salinity preliminary finding; one in the North Central Plains areas (for saline seeps) and the second in either the Coachella or Lower Rio Grande Valley (for saline irrigated agriculture). Truck radar HH and HV data at L-band and C-band (10° to 40°) is required at three times during the growing season, with supplementary aircraft scatterometer L-band and C-band, HH and HV, 15° to 25°, data at the same times. Aircraft L-band and C-band SAR imagery would also be acquired at the same times. A relative calibration of $\pm$ 2 dB is required for aircraft SAR imagery; a geographic registration of $\pm$ 20m is required for the saline seep measurements and $\pm$ 100m for irrigated fields. Multi-temporal merging of aircraft SAR data is required, along with improved methods of obtaining rapid measurements of electrical conductivity of ground-truth soil samples.

Image Analysis and Pattern Recognition Techniques - This research need would be addressed by the development of image analysis and pattern recognition techniques for use with X-band and K-band aircraft SAR imagery taken at 10-30 day intervals to coincide with MSS and TM passes, and with 10-20m resolution, prior to speckle removal. No other aircraft or truck data would be required. A relative calibration of $\pm$ 2 dB is required. There would be multi-temporal merging of aircraft SAR data alone, along with multi-temporal merging of VIR data alone, single-pass merging of VIR and SAR data, and multi-temporal merging of VIR and SAR data. Data processing algorithms would be developed which would separate speckle effects from the true meso-texture of the scene. Techniques would be developed to relate statistical classes within radar imagery to statistical classes intrinsics to crop land, forest, and rangeland scenes.

Land Cover

Establish Data Base of Urban and Rural Microwave Spectra - The present evidence of the potential of radar remote sensing to contribute significant information for land use/land cover investigations is based on a small set of independent radar images. These indicate that radar backscatter is extremely sensitive to the regular shapes characteristic of urban areas. The data also suggest that the depolarized component in radar backscatter is distinctly different for cultural targets versus natural targets. However, almost no data suitable for quantification of these effects presently exist.

The data base required includes aircraft scatterometer measurements at P, L, C, X, and K-bands, all polarizations, and a range of incident angles from 10° to 60°. In addition, because urban scenes do not lend themselves to truck-based sensor measurements, these type data must be acquired using helicopter-mounted sensors. These should be of the spectrometer type in the range 1-18 GHz.

Relating Radar Parameters to Land Cover Factors - A systematic analysis of urban/suburban environmental and temporal land cover characteristics as recorded in radar image data is required. This can be accomplished by first obtaining synoptic, high quality SAR images over eight urban areas once during each of four seasons in a one year period. The primary data base required includes multi-frequency (L, C, and X-band), multipolarization aircraft SAR imagery. In addition, aircraft multiparameter scatterometer data are desired to extend the core data base previously specified.

Determining Cartographic Properties of SAR Data - There is a need to determine the compatibility of SAR data with National Map Accuracy Standards at scales of at least 1:250,000. This will require spaceborne SAR data for two ascending and two descending orbits over flat, undulating, and mountainous terrain.

Water, Ice, and Snow

Determining Hydrologic Applications of Radar Data - As was discussed in the Water, Ice, and Snow Panel report, this objective involves several tasks. The data needs include a wide range of sensor systems, including Seasat SAR, airborne SAR, aircraft scatterometers, and ground-based radar systems. Of particular importance in this research need is improved quality of measurements and increased data processing capability. An area of special concern is research on soil moisture measurement capabilities. The ongoing research effort on this topic has been handicapped by an inability to obtain usable scatterometer data for analysis even after the data have been flown. Delays of over a year have been common. This situation affects all of the proposed research tasks, and if new sensor systems are acquired, as recommended in this report, the problem will become acute unless a substantial improvement in data processing facilities is made.

Determining Radar Sensitivity to Snowpack Conditions - The present understanding of the influence of snowpack properties on radar backscatter is based primarily on limited truck-based radar data. The existing airborne radar data are inadequate to support quantitative analyses. Consequently, extensive data acquisition is required to meet this research need. The data required includes spaceborne SAR (Seasat and SIR-A), airborne SAR (L, C, X, and K-band), aircraft scatterometer (L, C, X, and K-band, 10° to 50° incident angle), and ground-based spectrometer (1-18 GHz) measurements. The airborne radar image data should have a relative accuracy of $\pm$ 1 dB and should be digitally processed.

Documenting Characterization of Floating Ice - Although the understanding of the interaction of radar energy with floating ice is reasonably well documented, there exists a need to extend this basic understanding to a stage where effective, synoptic monitoring can be accomplished. This requires the acquisition of controlled data sets of areas of special interest, e.g., ice edges in the Arctic. The data needs include airborne SAR (L and X-band), airborne altimeter, and airborne scatterometer (L, C, X, and K-band) measurements. In addition, a 100-200 MHz sounder is desired for operation from the Space Shuttle to permit the determination of bedrock topography of Greenland and Antarctica.

SYSTEMS REQUIREMENTS

A review of the requirements for radar systems, data processing improvements and other active microwave technology developments clearly shows that certain of these systems development needs are shared by several of the applications areas and may be viewed as a common denominator to a viable program of active microwave research. Many of the radar sensors and data processing techniques are already partly or fully operational. However, a number of new frequencies, polarizations and platforms that are not now in the planning stages will be needed if all of the requested research needs are to be met.

The list provided in Table 8 is a summary of imaging and non-imaging radar systems which would meet the previously stated research needs.

The mere existence of these radar systems does not insure that the research needs outlined by the applications panels will be met. There are other crucial elements to meeting the research needs. For example:

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Table 8

SUMMARY OF REQUIRED IMAGING AND NON-IMAGING RADAR SYSTEMS

Seasat: L-band, 20°, HH
SIR-A: L-band, 45°, HH

Aircraft Imaging Radars (NASA-operated)

WB-57 X-band SAR (JSC), VV, VH, HV, & HH
WB-57 C-band SAR (JSC), VV, VH, HV, & HH
CV-990 L-band SAR (JPL), VV, VH, HV, & HH
K-band SAR or SLAR (non-existent), VV, VH, HV & HH
Multifrequency (L, X, S, X and K-band) multi-polarization SAR (non-existent)

Aircraft Scatterometers

C-130 P-band Scatterometer, VV, VH, HV, & HH
C-130 L-band Scatterometer, VV, VH, HV, & HH
C-130 C-band Scatterometer, VV, VH, HV, & HH
C-130 X-band Scatterometer, (non-existent)
C-130 K-band Scatterometer

Helicopter Scatterometers

L-band Scatterometer, dual-polarization
C-band Scatterometer, dual-polarization
X-band Scatterometer, dual-polarization

Note: This system would be a portable strap-on package for use with locally-available rental helicopters.

Truck Scatterometers

1 - 18 GHz, dual-polarization, 5° - 70° (K.U. MAS)
1 - 18 GHz, dual-polarization, 5° - 70° (JPL) - under development
L, C, X, K-bands, dual-polarization, 5° - 70° (add X-band to JSC truck system)
L, C, X-bands, dual-polarization, 5° - 70° (add C and L-bands to TAMU system)
1 - 18 GHz, MAS, dual-polarization, 5° - 70° (new system)

Table 9

EXISTING SYSTEMS

Category	Organization	Frequency	Polarization	Angle of Incidence	Processing	Status
Truck-based	KU	1-18 GHz	Dual			Operational
	JSC	L, C, K	Dual	5° to 70°		Planned
	TAMU	L	Dual			Planned
	JPL	1-18 GHz	Dual		Digital	Under development
Helicopter	KU					Needs system integration support
Aircraft Scatterometers	JSC	P, L, C, K	Dual except K	5° to 60°		Operational
Aircraft Imaging Radars	JPL	L-band	Dual	0 to 60°	Optical/ digital	Operational
	JSC	C, X	X dual, C, HH	X 10° to 60° C 10° to 35°	Optical	Operational
	(ERIM)	L, X			Optical	Operational
	(Goodyear)	X			Optical	Operational
	JPL/JSC	1-12 GHz	Dual	10° to 60°	Digital	Under development
Shuttle Imaging Radar	SIR-A	L	HH	45°	Optical	Under development

1. Both image and non-image data must be carefully processed to provide final data products in a form which has clear quantitative meaning in terms of radar cross section and location. Furthermore, processing techniques must be developed which allow merging of data for multi-temporal, multi-frequency and multi-polarization comparisons and composites. This requires careful attention to system calibration and registration, which in turn demands a substantial engineering development effort.

2. A second element is the recognition that for those high priority applications areas for which systems are designed, a very substantial investment must be made in data analysis and interpretation after the radar system has been shown to function properly. Unfortunately, in the past, this analysis/interpretation element has been poorly funded in relation to the sums spent on the radar system development so that the eventual or potential utility of the data for which the system was designed has often not been conclusively demonstrated.

3. A third element or philosophy implicit in most of the research needs is the assumption that truck and aircraft scatterometer basic data, when supplemented by aircraft imagery, can be used to provide a convincing case for the utility of spaceborne SAR data in meeting basic information needs. However, for any given specific proposed synoptic data need such as the measurement of snowpack water content, it must also be demonstrated that SAR system design parameters can be identified which will eventually lead to spaceborne imagery which can be used to measure snowpack wetness. In other words, after truck or aircraft data have established a sensitivity of radar data to a scene characteristic, it will then be necessary to define and verify spaceborne SAR parameters required for that application.

There is a need common to almost all of the requirements for SAR imagery for preprocessing procedures which is to (a) reduce data dependence on look and incident angles, (b) eliminate atmospheric effects, (c) reduce speckle effects, (d) geometrically register imagery with standard projections, (e) eliminate topographically induced image distortions at the higher frequencies, and (f) identify the effect of resampling after these preprocessing corrections. For aircraft scatterometer data, digital processing procedures must be used which correct for the aircraft flight parameters and which provide calibrated profiles of radar scattering coefficient versus a nadir time which can be easily related to ground location by correlation to photographic images. Finally, in addressing the widespread research need for merged imagery from a variety of sensors, there is a requirement to examine the feasibility of standard merged projections and to document the data processing tasks necessary to support this requirement.

EXISTING RADAR SYSTEMS

Table 9 is a much simplified summary of the radar systems which are now either in existence or which are under development. It is especially noteworthy that there are no operational helicopter-borne scatterometer systems in existence, and that most of the aircraft imagery is presently processed by optical techniques.

REQUIRED TECHNOLOGY DEVELOPMENTS

In view of the previous two sections, it is apparent that additions to the present complement of scatterometers and imaging radars are needed if all of the applications needs are to be met. A summary of needed technology developments, as derived from the previous discussion, is presented in Table 10, without ranking by priority in terms of research needs.

Truck-based Scatterometers - It is clearly apparent that the present truck-based scatterometer systems cannot cope with either the data quantity or the timeliness required for meeting the research needs of the applications areas. Truck-acquired measurements of the radar scattering coefficient are crucial to basic research needs in the areas of crop land, soil moisture, rangeland vegetation, quantitative geology, hydrology, and snowpack investigations. The only fully operational truck-based 1-18 GHz spectrometer is the University of Kansas system. In order to take advantage of other truck systems which have partial capability, it is recommended that an additional X-band dual-polarized channel be added to the NASA/JSC system, and that both C and L-band channels be added to the Texas A & M truck system. The JPL 1-18 GHz truck-based spectrometer should be completed. In view of the fact that these four systems might still be unable to meet the stated research needs, an entirely new truck scatterometer university-based research facility may be required. This would serve the purpose of complementing the present optical reflectance measurements and also corroborate and extend the results which have been obtained with the Kansas system. This should be a 1-18 GHz spectrometer.

Aircraft-based Scatterometers - In order to answer the research needs for basic information on optimum frequencies for crop land, forest and geology remote sensing, it will be necessary to add an X-band dual-polarization scatterometer to the NASA/JSC C-130 aircraft and also to add cross-polarization capability to the present K-band scatterometer.

Helicopter-based Scatterometer - Basic research needs for fundamental data in the areas of forest and urban land cover remote sensing require scatterometer data over a wide angular range from a platform that can either hover or traverse over selected areas. In order to minimize total systems cost, this scatterometer system would be used as a strap-on package for use with locally available rental helicopters.

Aircraft SAR Imagers - The present NASA/JSC C-band SAR acquires data in the HH mode. Dual-polarization capability should be added to this WB-57 imager. Digital processing capability is needed for all aircraft SAR imagery, including the JPL L-band SAR which at present has limited digital processing capability. In order to answer fundamental questions on optimum frequencies (X versus K-bands) for radar remote sensing of crop lands, a new K-band aircraft-based SAR may be required. Since this would require a completely new system development which would be relatively costly, a recommendation for the engineering development of such a system would come only after a careful examination of X and K-band aircraft scatterometer data showed that there was justification.

Basic Engineering Technology Development Efforts

In addition to the above specific radar systems, there are numerous fundamental technology efforts which are necessary in order to support the research needs of the applications areas. These can be broadly grouped into (1) system calibration and data processing and (2) advanced engineering systems. Of these two general areas, the most important task is the calibration and standardization of data from existing aircraft scatterometer and imaging radars. This means that reliable, calibrated and standardized data must be available from the present complement of sensors in order to make meaningful quantitative measurements. After demonstrating the potential of the present instrumentation to provide repeatable measurements, implementation of advanced engineering systems concepts such as multi-frequency, multi-polarization, calibrated SAR sensors can proceed.

The technology panel has addressed several tasks which can be grouped under these two headings, as summarized below:

System calibration and data processing

1. Establish system calibration standards in relation to

Table 10

NEEDED TECHNOLOGY DEVELOPMENTS
(not ranked by priority)

Category	Organization	Frequency	Polarization	Angle of Incidence	Processing	Status
Truck-based	JSC	X-band	Dual	5° to 70°		Add to present system
	TAMU	C, L	Dual	"		"
	JPL	1-18 GHz	Dual	"		Complete
	University	1-18 GHz	Dual	"		New
Scatterometers	JSC	L-band		"		Replace outmoded L-band hardware
	JSC	X-band	Dual	"		New X-band system
	JSC	K	Cross	"		Replace outmoded K hardware, add dual polarization
Helicopter	JSC/KU	L-band and 1-18 GHz	Dual	"		Adaptation of KU system
Aircraft	JSC	C-band	Cross	10° to 60°		Add to present
	JPL	L-band			Digital	Add digital processing to present L-band
		K-band	Dual	"		New

user needs.

2. Image quality standardization for SAR imagery.
3. Preprocessing at pixel level of SAR imagery.
4. Determine system accuracy requirements for radar stereo imaging.
5. Determine effect of azimuth radar return dependence on image calibration.

Advanced engineering systems concepts

1. Development of high capacity, high quality SAR processor facility.
2. Development of squint-mode multiple beam SAR systems and use of advanced digital processing device technology.
3. Studies of bistatic radar in remote sensing.

Each of these engineering development efforts can be considered supportive in some sense of the general research needs of the applications areas, even though those efforts may not be specifically requested in the form given above. It is not always possible to make clear judgments assigning priorities to these basic engineering development efforts in a way which relates directly to the stated research needs, and this report makes no attempt to do so.

TECHNOLOGY DEVELOPMENT PLAN

The technology development plan presented here is designed to meet the broadest base of high priority applications research needs using both existing and new radar systems and associated data processing techniques. It is structured through four broad development tasks, each of which encompasses specific subtasks. These development tasks are:

1. Improvements to present radar systems.
2. New truck and aircraft systems.
3. Data processing and calibration techniques.
4. Advanced radar systems.

TASK I: Improvements to Present Radar Systems

This development task encompasses seven subtasks, all of which are designed to produce a substantial improvement in the capabilities of the present truck and aircraft radar systems to produce reliable and quantitatively meaningful data products. This would be accomplished by replacing outmoded and unreliable hardware on two of the existing aircraft scatterometers, by adding additional frequency bands to the JSC and TAMU truck systems, by completion of the JPL 1-18 GHz truck microwave spectrometer, by adding dual-polarization capability to the JSC C-band SAR, and by adding high capacity digital processing capability to the L, C, and X-band aircraft SAR systems.

The backbone of the NASA active microwave remote sensing program is the complement of existing truck-based and airborne scatterometers and SARs which are operated from NASA/JSC, JPL, KU and TAMU. These sensors will continue to be the prime sources of data for the next several years. In order for these radar systems to fill the stated research needs of the applications areas, they must be made much more reliable and data efficient than has been the case in the past; furthermore, there are missing microwave bands on each of the platforms that must be filled in order to meet an expected increase in user load.

The technical objectives of this development task are to:

A. Add an X-band dual-polarized scatterometer to the NASA/JSC truck system.

B. Add C and L-band dual-polarized scatterometer channels to the TAMU truck system.

C. Complete the JPL 1-18 GHz truck-borne active microwave spectrometer.

D. Replace outmoded hardware on the NASA C-130 L-band scatterometer.

E. Replace outmoded hardware and add dual-polarization capability to the NASA C-130 K-band scatterometer.

F. Add digital processing capability to all aircraft imagers.

G. Add dual-polarization capability to the WB-57 C-band SAR.

Subtask A: X-band dual-polarized scatterometer for JSC truck system

The specific objective of this subtask is to provide an additional channel which, taken together with the K-band existing channel, will provide X versus K-band basic radar response data for use in addressing stated user needs in crop land, forest, rangeland vegetation, geological studies of radar return from lineaments, soil wetness, and snowpack investigations. With such a wide range of research requirements for truck data, it is clear that the present Kansas and JPL truck systems cannot cope with the volume of basic data required. The least expensive solution to this problem is to upgrade and supplement the other existing truck systems. The scatterometer design would be a modified version of the FM-CW radar used in other bands. When completed, this would mean that the JSC system would have full dual-polarization coverage from 10° - 60° angle of incidence at L, C, and K-bands.

Subtask B: C and L-band dual-polarized scatterometers for TAMU truck system

This addition to the existing Texas A & M (TAMU) active/passive truck system has the same objective as that of the JSC truck system. The present TAMU system has X-band scatterometer capability, and the addition of C and L-bands would bring this instrument to maturity for use in supporting a wide variety of research needs for truck-acquired radar data.

Subtask C: Complete the JPL 1-18 GHz truck-based active microwave sptrometer

Subtask D: Replace outmoded hardware on the NASA C-130 L-band scatterometer

This scatterometer is an aging radar built in 1969. It has had a long and notorious history of equipment and antenna failures which stem primarily from materials problems. The antenna must be replaced if the L-band scatterometer is to become a reliable source of data; other system modifications and replacements are also necessary.

Subtask E: Replace outmoded hardware on the NASA C-130 K-band scatterometer and add dual-polarization capability

This scatterometer has also experienced numerous failures which are related to a need for modernization of the components. At present it is singly polarized. It will need an additional channel and antenna to bring the instrument into dual-polarized operation. This capability is especially needed to support basic research needs in the radar studies of crop lands.

Subtask F: Add digital processing capability to all aircraft SAR systems

At present, the JSC C and X-band SAR system, and the JPL L-band SAR imagers use primarily optical data processing. However, in order to meet the demand for aircraft acquired imagery for use in detailed quantitative studies at the pixel level, it is necessary to replace the present optical processors by digital processors. Although some of the JPL L-band aircraft SAR data has been processed by the Seasat processor, this is a very slow and inefficient means of obtaining digital representation of the imagery. At present,

TASK I: Schedules and Estimated Level of Effort

Subtasks	Year 1	Year 2	Year 3	Year 4	Year 5
A. X-band truck scatterometer JSC		30K			
B. C and L-band TAMU scatterometer		100K	75K		
C. Complete JPL 1-18 truck scatterometer	70K				
D. Upgrade C-130 L-band scatterometer		250K	100K		
E. Upgrade C-130 K-band scatterometer		250K	100K		
F. A/C SAR digital processor			350K	200K	150K
G. C-band SAR dual			300K	50K	

NASA/JSC is implementing a limited capacity digital laboratory-based processing facility. However, this would not be able to handle the large volume demand for high quality imagery such as required to meet the stated research needs. The digital processing facility proposed here would handle L, C, X, and K-band SAR data and insure processing to a uniform standard.

Subtask G: <u>Add dual-polarization capability to the WB-57 C-band SAR</u>

The present C-band WB-57 SAR is operated as an HH polarized imager. Full dual-polarization capability is needed to meet the stated research needs in remote sensing of forests, rangeland vegetation, soil salinity, geologic surfaces, land cover, and snowpacks.

TASK 2: <u>Truck and Aircraft Radar Systems</u>

Subtask A: <u>Addition of dual-polarized K-band SAR to WB-57</u>

This K-band SAR would provide dual-polarized aircraft imagery which would be complementary to the presently available X-band SAR imagery. The design would emphasize the ability of the aircraft system to directly compare X-band and K-band radar imagery for critical research needs in crop land, forestry and geology remote sensing where optimum frequencies and polarizations suggested by truck data have not yet been substantiated by quantitative comparisons of K-band with X-band imagery. It should be noted that this is a relatively expensive procurement, since no off-the-shelf K-band synthetic aperture radar systems are presently available. (Some components of a real-aperture K-band system are available at JPL, but it is doubtful that quantitatively meaningful image comparisons could be made between synthetic aperture X-band images and real aperture K-band images.) The level of effort proposed here is based on using some of the electronics hardware from the modified Goodyear APQ-102 X-band system and supplementing this with two new K-band shaped beam antennas, one for each polarization.

Since this is a relatively expensive hardware procurement, it is recommended that if a start is made it be postponed for three to four years, after the results of the X-band and K-band C-130 scatterometer data flights over geological and agricultural test sites become known. If the results of these scatterometer flights suggest strongly that K-band imagery would be greatly superior to X-band imagery for meeting these research needs, then a K-band imager could be recommended.

The first technical objective of this development task is to examine the results of X-band and K-band scatterometer aircraft missions over agricultural and geological test sites to determine the relative radar return sensitivity of K-band as contrasted to X-band. The second objective would be to make a careful judgment of whether, in view of the coherent nature of SAR imagery, a K-band aircraft SAR could be designed to provide the same measure of relative sensitivity with respect to an X-band imager. Finally, if these two first steps justified such an engineering development, the hardware procurement would be initiated.

Subtask B: <u>Addition of X-band dual-polarized scatterometer to C-130 aircraft and addition of on-board scatterometer data processing facility for all frequencies</u>

The present complement of scatterometers on the C-130 aircraft cover L, C, and K-bands in either dual or single polarization modes. Because of the basic research need for data comparing X-band radar return to that from K-band, e.g., in studies of crop lands, and because optimum angles suggested by truck data have not been corroborated by aircraft data, this additional band would complete the frequency coverage of the C-130 system. In addition, the JSC-TAMU scatterometer data processing facilities would be upgraded to provide better quality and more timely data products associated with all of the scatterometer bands.

This development task would be carried out over a two-year period and would consist of two technical objectives: (1) the addition of an X-band Doppler scatterometer with dual-polarization capability to the NASA C-130 aircraft, and (2) additions and improvements to the JSC-TAMU scatterometer data processing facilities which would provide high quality, timely scatterometer data products for all of the scatterometer bands.

Subtask C: <u>Adapt L-band and 1-18 GHz dual-polarized KU helicopter-borne strap-on scatterometers, and develop 1-18 GHz microwave active spectrometer</u>

The objective of this development task is to create new basic research scatterometer instruments for the acquisition of radar return data to support research needs in radar studies of crop lands, forestry, land cover and other similar investigations. Particularly for land cover and forestry cover studies, the maximum length boom for any truck systems would be too short to produce radar return data which could be classified as true far-field data. Although aircraft scatterometry data are supplementary to helicopter

TASK 2: <u>Schedules and Estimated Level of Effort</u>

Subtask	Year 1	Year 2	Year 3	Year 4	Year 5
A. K-band hardware development				500K	300K
B.1 Add X-band A/C scatterometer		250K	100K		
B.2 Upgrade scatterometer data processing	L, C bands 100K	X, K-bands 100K			
C.1 Helicopter scatterometer development		50K			
C.2 New 1-18 GHz truck-borne MAS			300K		

data for these purposes, the aircraft cannot dwell on specific scenes of interest in urban and suburban land cover investigations. Since helicopters are quite expensive, it is proposed to use locally available rental helicopters and to use an existing L-band and 8-18 GHz scatterometer available from the University of Kansas which would be modified to be used as a strap-on instrument.

The second element of this plan would be to create a new truck-borne microwave active spectrometer with 1-18 GHz coverage and full polarization and angular capability. The new truck MAS system would be used as the basis for a new university-based facility for the acquisition of basic radar return data to support a wide variety of research needs that call for a volume of data that cannot be met by the existing KU system and the future augmented JSC, JPL and TAMU truck systems.

The present Kansas scatterometer system, which has been used on previous helicopter missions, would serve as the basis for meeting the research needs for helicopter-borne scatterometer data. Some funds have been requested for system integration, calibration, and data processing activities necessary to bring the system up to operational status.

The new 1-18 GHz truck-based system would be designed along the lines of a similar 1-18 GHz JPL system presently under development. Such a system would be based at a university which has both the background experience in the objectives of remote sensing and the necessary engineering expertise to develop and maintain the microwave system and data processing aspects of the facility.

TASK 3: Data Processing and Calibration Techniques

This task encompasses five subtasks:

A. Calibration and standardization of active microwave sensors.

B. SAR image quality/image registration and translation into system specifications.

C. Pixel preprocessing of SAR imagery.

D. Radar stereo theory and techniques.

E. Azimuth angle dependence of radar backscatter.

Subtask A: Calibration and standardization of active microwave sensors

Calibration methods and standards will be developed in order for data sets from different time periods and for different sensor types to be compared with confidence that any differences noted are true measured phenomena and not due to differences in sensor calibration.

Data sets obtained [illegible] two different systems often yield conflicting data valu[illegible] the orderly development of measurement needs it [illegible] to have a data set that is decoupled to any [illegible] stem and only see the effects of the surfa[illegible]

In order to compare existing active microwave data from diverse sensors and assure the accuracy and compatability of any future data, it is necessary to develop calibration standards and procedures applicable to ground-based, aircraft-based, and spaceborne imaging radars, scatterometers and spectrometers. It is proposed that this study also provide adequate support to allow for the cross-calibration of all relevant existing active microwave sensors, particularly those participating in any ERSAR study programs.

The objectives of this subtask are:

1. Conduct a thorough literature search and consult with researchers in various organizations (such as, but not limited to, JSC, JPL, ERIM, GSFC, KU, UMC, TAMU) to ascertain techniques and accuracies currently employed to calibrate active microwave sensors.

2. Define and fabricate, if necessary, a set of primary radar standards for both point targets and distributed targets, which is generally acceptable to the user and engineering communities, and develop the appropriate experimental techniques required for proper utilization of these standards. Particular attention is called to the difficulties associated with the fabrication of appropriate extended targets, and the potential expense associated therein. Careful consideration will thus be given to existing man-made targets as well as natural targets.

3. Conduct system studies and develop prototype hardware where required for secondary radar standards. These portable standards will always accompany active microwave sensors. They fall into two categories: (1) passive standards (conducting spheres, Luneberg Lens, and corner reflectors), and (2) active standards (calibrated noise sources). Particular attention will be focused on the active secondary calibrators since these will typically accompany SAR missions, and a diverse collection of these devices currently exists.

4. Provide financial and technical support to relevant existing active microwave systems to facilitate their cross-calibration. Produce documentation that will set requirements for future NASA-funded instruments. It is suggested that, where possible, two or more of any type radar, e.g., X-band aircraft, be cross-calibrated to assure the accuracy not only of the radars themselves, but the standards as well.

5. Extensive facility support is required. Access to one complete set of equipment (L, C, S, X-band radar scatterometer) is probably required for developing the primary and secondary standards. Close cooperation of all other sensor groups is required to permit cross-calibration of the various instruments.

The total estimated level of effort over a 4-year period is 10 man years. In addition, it is anticipated that approximately \$150K will be required in procurements and support contracts.

Subtask B: SAR Image quality/image registration, and translation into system specifications

The objective of this study is to arrive at a uniform set of SAR image quality standards or definitions and where applicable, translate these into system specifications. This objective will be met by organizing a working group of recognized experts from each of the major organizations doing research in SAR systems. Where applicable, the definition of the image quality parameters will be translated into system specifications. The expected result of this study is a document defining, unambiguously, each of these parameters. These parameter definitions will subsequently be used in the calibration of instruments.

A uniform set of image quality parameter definitions, used by both users and system designers, does not exist. System calibration must be made to a commonly used set of standards in order to have meaning.

A working group of representatives of organizations doing radar technological research and one representative from each of the following areas: Geology; Agriculture; Land Cover; and Water, Ice, and Snow will convene. This effort will be subdivided into four separate tasks:

1. Parameter Identification: A set of parameters meaningful to users and measurable to technologists will be defined.

2. Parameter Definition: These parameters will then be unambiguously defined consistent with measurement techniques available.

3. Measurement Requirements: A set of image measurement requirements will be arrived at so that it is possible to measure the desired image quality parameters consistent with the definitions.

4. Where applicable, these parameters will be translated into system specifications or requirements.

This subtask also includes a study of the limits of position registration for spaceborne and aircraft SAR systems to determine the current state-of-the-art and techniques for post-image registration.

The land cover and agriculture panels have stated that in order to study the effects of land use with time, it is necessary to gather data over a period of time and register

images obtained at different times on a pixel by pixel basis. The ability of a SAR system to accomplish this is limited by platform errors (position, time) and SAR system timing errors. Before reliable pixel registration can be made, these errors must be identified and their values estimated. Once identified, techniques for improving registration can be defined.

The various error bounds for pixel registration will be identified, and using a representative system design, their contribution to position location estimated. Using the nature of the resultant errors (linear, quadratic, etc.) existing correction algorithms can be identified or, if not, the requirements for them will be given. The sources of pixel position errors will be identified as well as the procedures necessary to correctly register SAR data to a given required projection.

This subtask will require a 4 man-year effort over a one year period.

Subtask C: Pixel processing of SAR imagery

The definition of pixel processing encompasses all digital processing after image formation and prior to specific image analysis applications within the various disciplines. The objectives of this subtask are to develop and evaluate specific digital processing techniques which could be used to present a user with a usable, refined digital SAR image. It is assumed that this digital image is required by an applications group for analysis to meet their specific need. Included in this effort should be development of algorithms which have generalized preprocessing applications which transcend the specific application. For the benefits of active microwave imagery to be fully realized, NASA will necessarily have to supply the user community with SAR data in a similar manner as Landsat imagery is now supplied. It is important to begin this activity in time to make beneficial impact to the utility of SIR-A Follow-on, where digital images will be obtained from space in high volume.

The approach for this research should focus on algorithm development for general purpose SAR applications to remove known distortions (geometric and radiometric) in the imagery. In order to evaluate the utility of the algorithms, some example imagery must be processed. Seasat imagery should be used, as well as certain aircraft SAR data for initial verification of the algorithm.

The expected results of this subtask are a package of pixel processing algorithms for preprocessing SAR digital imagery which could then be treated similarly to Landsat type images. These algorithms should include: (1) image rectification, (2) registration, (3) geometric correction, (4) calibration manipulation, (5) minimizing radar specific effects such as image dependence on angle of incidence, speckle, etc, (6) compensation for a priori topographic effects, and (7) other possible planimetric corrections for map-type applications. Not all of these algorithms need be employed on all SAR images, but they do transcend any one specific application and should, therefore, be results of a general effort. In addition, a system specification for a complete hardware/software facility to handle preprocessing of SAR images from space in the future should result from this research program.

Justification for this subtask revolves around the cost-effective approach of providing these general preprocessing abilities in a central facility to efficiently produce SAR digital imagery in a user compatible format. The general utility of SAR images in the application community should be greatly enhanced by the product of this research program. Further justification can be made by citing previous NASA workshops which have yielded similar recommendations. In addition, the Applications Group Workshop Report points out specifically in Agriculture, Geology, and Land Cover Application areas the need for geometrically corrected images that could be registered with Landsat images to improve classification probabilities.

The technical objectives of this subtask are to develop and evaluate pixel processing algorithms to be used in a preprocessing phase prior to specific applications of image analysis techniques by the various disciplines. This pixel processing is required after the image formation phase for the purpose of providing a broad user community with digital images more easily applied to, and integrated with, existing image processing capabilities. A third objective is to define and specify a hardware/software facility that could feasibly handle SAR data from follow-on SIR-A flights.

The experiment design should include developing algorithms to provide proposed preprocessing needs and evaluate those algorithms on examples of digital SAR images presently available. These algorithms should be initially designed for implementation on an available computer facility, consistent with a definite design goal of implementation on the most effective processing facilities achievable in the SIR timeline. Multiple parallel processors and other "super machines" should be considered. After development of a set of pixel processing algorithms, a special dedicated hardware facility should be specified for implementation to accompany and support SIR flights.

This effort addresses the development and evaluation of a set of algorithms. These algorithms should be developed independently so that they may be independently invoked, since not all applications/scenes would require all preprocessing corrections to obtain a suitable image. The algorithms are:

Image Rectification: This algorithm should seek to compensate for misalignment of the antenna with the ground track for SAR imagery.

Geometric Correction: This algorithm should compensate for geometric distortions introduced from producing a two dimensional representation from a three dimensional object. If these distortions can be removed, the SAR image will have each pixel at a correct ground plane location. This image could then be utilized with map products and a universal coordinate system such as UTM.

Image registration: This algorithm would allow two images of the same ground path to be registered with one another. The images both might be SAR images for correlative studies, or one image might be some visual or infrared image. Digital resolutions and spatial resolutions must be handled within this algorithm.

Radiometric Corrections: This class of algorithms should address the issue of variations in backscatter amplitude and/or power due to radar effects alone. These algorithms should produce an image with gray level variations that represent subject image variations alone and knowledge of radar parameters could then be ignored for image interpretation.

Calibration: This algorithm should seek to calibrate from known target reflector data the image gray level response.

Topographic Compensation: As topographic data are known, this algorithm should compensate for the non-uniform backscatter response inherent in topographic imaging.

Angle of Incidence: Removal of gray level dependence on angle of incidence is the goal of this algorithm. Removal of this radiometric distortion allows treating multiple images alike and acquiring a consistent radar signature.

Additional algorithms should be developed to facilitate the correlation of SAR images with maps and other remotely sensed data.

The evaluation efforts must focus on proving these algorithms on existing digital SAR imagery whenever possible. Geometric correction evaluation and registration evaluation should be made based on ground-truth maps at several selected scenes. The evaluation should quantify misregistration with base maps and justify the measured geometric error.

Radiometric correction evaluation should include image evaluation of several scenes that show variations known to correlate with ground-truth data independent of radar

parameters which influence image gray level.

This research subtask should be completed in a two year span. This schedule should be synchronized with the SIR program.

This research program requires facilities to produce digital Seasat imagery and available aircraft digital SAR images. In order to evaluate the developed algorithms, an image processing facility must be available which can accommodate Seasat type digital images. Several of these exist for the development phase. The design goal of a high speed machine need not be supported at the onset of this research program, but could be delayed pending favorable evaluations of the proposed products.

Computer time processing might well be significant in the pursuit of this research subtask. An estimate is highly dependendent on the number of scenes to be evaluated, the type of computer utilized and many other factors influencing costs of processing. For a schedule of two years to completion, a magnitude of 6-10 man years is expected.

Subtask D: Radar Stereo Theory and Techniques

The objectives are to optimize aircraft flight and orbital parameters and to determine system accuracy requirements for radar stereo imaging. The need for stereo data was expressed directly by the Geology Panel, and indirectly by the other panels in the Applications Group Workshop. The geology need is primarily the provision of a visual three-dimensional model for interpretation. The other panels needs are related to the provision of topography to remove slope variations in backscatter measurements and to remove elevation displacements in cartography when the topography data are not available elsewhere.

The approach is to derive sensitivities and postulate parameters by analysis, and to verify sensitivities and quantify parameters by flight test with airborne and spaceborne systems. The data will be interpreted by scientific personnel to select optimum parameters.

The expected results will be the provision of hardware design data and orbit selection appropriate to stereo data collection for future operational systems.

The approach provides interaction between system designers and scientists so that an economical balance between system complexity, data acquisition costs, and data utility can be obtained in an operational system. The analysis is required to guide the test planning and evaluation. Airborne tests are required to provide a wide variety of aspect angles and, thus, stereo parameters. Satellite tests are required to assess the effect of relatively constant stereo parameters over the swath.

It is possible in principle to form a stereo model by viewing images made from any two significantly different flight paths. Past experience has shown that the psychophysical processes involved will permit reliable formation of a stereo model only when the two flight paths are substantially parallel and on the same side of the area being viewed. Otherwise, differences in shadowing and terrain illumination make fusion (psychophysical model formation) difficult or impossible. It is known that the vertical exaggeration of the model seen and the sensitivity of the process increases with increasing incident angle differences (convergence angles), at least up to thirty degrees or so. The sensitivity to lack of parallelism and the maximum or optimum convergence angles are not known, nor is the dependence of these maxima or optima on average incident angles. One objective is to explore these angular variables for optimum interpretability.

Because the psychophysical phenomenon involved is very sensitive to image geometry changes due to elevation displacement, it is also very sensitive to image geometry changes due to system imperfections. The sensitivity to such imperfections is known qualitatively, but analysis and psychophysical testing must be done to quantify the effects and derive end-to-end system geometric fidelity specifications appropriate for stereo interpretation. Some modifications to test systems may be required to avoid masking fundamental sensitivity measurements.

In general, the accuracy of cartographic measurements made using the anaglyphic (psychophysical fusion) technique will be derived automatically as part of the previous process, and when a very dense sample spacing is required all of the restrictions and results will be applicable. However, statistical data have not been gathered to relate the horizontal and vertical accuracy of such measurements to system parameters and accuracies. An objective will be to obtain such data. Furthermore, when locations of only a few identifiable isolated points are required, psychophysical fusion is not required, and measurements may be made by scaling the imagery and computing point positions by trilateration. This is known as analytic stereo measurement. Since fusion is not required, imagery obtained from any two flight lines may be used provided the flight lines and other imaging parameters are known accurately. A further objective will be to derive analytic measurement accuracy as a function of imaging parameters, flight line or ephemeris accuracy, system accuracy and accuracy of calibration techniques.

Experimental data should first be collected by an airborne SAR of appropriate characteristics over selected test sites of geologic interest. At least two test sites should be selected, one of low (but not zero) relief and one of high relief. Ten to fifteen passes having different offsets and headings should be made. The resulting image data should then be subjected to geologic analysis using a forced pair comparison human factors test with five to ten subjects. The results would be analyzed to extract maxima and optima.

For the position measurement task, accurate aircraft position measurements should be made using precise positioning equipment. Otherwise aircraft flight lines will have to be determined from resection techniques which is tedious and of limited accuracy. These data would then be used both in same-side and opposite-side measurements to derive cartographic accuracy data for point position measurements.

The primary satellite data are expected to be supplied by the variable and selectable angle SIR flights in the 1983 time frame. The same geologic sites imaged earlier in the aircraft flights should be covered, and a similar data analysis procedure followed. Both collection and analysis can be somewhat abbreviated because the objectives are fewer; because satellite orbital parameters are expected to be much more stable; and because fewer variations in look angle will be available. Some limited data confirming feasibility has been obtained from Seasat imagery. However, data from two or three depression angles and three incident angles, two same-side and one opposite-side, should be collected. These data should be subjected to engineering analyses and limited psychophysical tests to confirm the results obtained earlier, both for image interpretation and point position measurement.

The required activities are: (1) analysis, to derive sensitivities and system accuracy requirements; (2) experiment design, to define flight lines and parameter variation and data analysis requirements; (3) aircraft equipment modification, to provide required geometric accuracy; (4) aircraft data acquisition over specified test areas; (5) aircraft data analysis, to derive optima, maxima, and measurement accuracies; (6) satellite data analysis, to assess advantage of stable operation and uniform incident angles; and (7) derivation of design data for future systems.

The aircraft tests and studies will supply basic general design data for future systems and specific experiment design data for the 1983 Shuttle reflights. The Shuttle flight data should be used to validate and refine the design data derived in the aircraft tests for future operational or test system design.

Use of an appropriate airborne system will be required, along with signal processing equipment, a stereo comparator, and precision image mensuration equipment. Ongoing satellite programs such as SIR reflights should be tasked to

collect supporting data. Ground data reduction would be common to satellite and aircraft data.

A 3-4 man-year will be required over a 3-year period exclusive of aircraft and satellite operation and radar signal processing (image formation and dissemination).

Subtask E: Azimuth angular dependence of radar backscatter

Much has been stated about the need to calibrate active microwave sensors, but little consideration has been given to the complex angular dependence of the backscatter of diverse targets, with the notable exception of the incident angle. It has recently been demonstrated that there is a pronounced azimuth angle backscatter dependence for certain classes of targets (predominantly agricultural and urban) which, if not identified as such, may lead to gross errors in data analysis. It can be reasonably surmised that at least in these cases there may also be a third angular dependence which will favor, for instance, HH versus VV polarizations.

It is proposed to use existing scatterometer, spectrometer, aircraft and spaceborne data, as well as a limited number of new aircraft flights to evaluate the pervasiveness of data contaminated by this effect. In addition, detection schemes that would allow either decalibration or expurgation of such contaminated data will be developed.

This study is an important companion to the calibration study since a highly calibrated radar is useless unless the full extent of a target's angular signature is understood.

There is a large inventory of existing aircraft imagery which is immediately capable of yielding data on the extent of at least the azimuth dependence on radar backscatter. Utilization of this data base is a cost-effective approach toward dealing with the problem. In addition, other existing data sets are readily available which were generated by airborne scatterometers and truck-mounted systems. Subsequently, controlled experiments will undoubtedly be required.

Initially, it is necessary to ascertain the prevalence of the azimuth effect to see whether substantial study is warranted. Secondly, it is necessary to develop an understanding of the cause of the azimuth effect, and to determine whether a third angular effect (which will probably translate into a favored linear polarization) also exists. Finally, techniques are required that will permit "blind detection" of data contaminated by these effects and either for decalibration (if possible) or expurgation of the data.

The required activities include:

1. Recorrelate a reasonable amount of aircraft data in an attempt to ascertain the pervasiveness of the azimuth angle effect. Review the literature for indications of the effect as a function of frequency and polarization. Review University of Kansas and JSC data for indications of the effect.

2. Using various active microwave sensor data (predominantly airborne), accompanied by ground-truth, theoretical analysis, and computer simulation, develop an understanding of the causes of the effect, and its frequency and polarization dependence.

3. Study techniques for "blind detection" of the effect. For example, a pronounced systematic change in apparent backscatter across several azimuth "looks" would indicate the presence of an anomaly.

From 2 above, the theoretical and experimental data should facilitate the generation of techniques that will allow compensating for the effect or, if impossible, for deleting the contaminated data from the data set.

From the previous three tasks, assess the residual uncertainties after decalibration and the impact of the uncertainties on the interpretation of the imagery.

This subtask will require a 1-2 man-year per year effort over 3 years, plus the cost of data acquisition.

TASK 4: Advanced Radar Systems

This development tasks includes three subtasks:

A. Development of high capacity, efficient SAR processor system.

B. Squint-mode multi-beam SAR and SAW/CCT technology study.

C. Bistatic radar investigation.

Subtask A: Development of high capacity, efficient SAR processing systems

Radar data processing to reduce SAR echo data into usable image format is a major bottleneck in radar utilization at the current time. To develop means for efficient image formation is one major technological objective to facilitate radar remote sensing application studies. This subtask summarizes a plan to develop a data processing system to meet application needs of SAR imagery, as well as to support certain specific radar remote sensing experiments which requires data processing. The technical approach to be taken in this subtask consists of (1) form an extremely flexible general purpose SAR processing facility to meet near term (1980-1983) SAR experiment needs; (2) conduct studies into midterm (1984-1986) SAR processing requirements, and investigate approaches to meet such needs; and (3) develop a more capable SAR processing system to support midterm earth resource oriented SAR application studies.

The end product of this subtask would be a SAR data processing facility which consists of a flexible general purpose SAR data processing and image manipulation system, and a more specific high throughput, high quality SAR processor. The system knowledge and experience on SAR image formation obtained by conducting this effort also provides much needed technical information in the planning and implementation of potential SAR missions in the late 1980's time frame.

Existing SAR data processing methods which include optical and digital means are characterized by a limited controllability of the output image quality or a limited throughput rate. A very flexible high quality image formation system is currently needed to support several near-term SAR aircraft experiments where pixel, polarization, and phase information are required. To meet a growing demand of SAR imagery to support various anticipated earth research tasks which involve data collected at various frequency bands and polarizations at various sensor elevations (aircraft to Shuttle), more capable SAR processing systems will be required. A phased effort through a definition study and a system implementation would provide such a facility to meet the SAR image formation requirements in mid-1980 time frame.

The technical objective of this effort is to develop means to meet SAR image formation needs in the early 1980's. A four-year plan is formulated which consists of the following three major activities:

1. Development of an extremely flexible general purpose SAR processing facility to meet near-term (1980-1983) SAR experiment needs. This flexible facility would be able to process both spacecraft (Seasat) and aircraft SAR data to various controlled quality and to be able to retain various relevant information such as pixel phase and precision registered pixels of different radar frequencies and polarizations. This facility would allow investigators to experiment with SAR imagery parameters, e.g., number of looks and resolution, and to investigate advanced SAR remote sensing concepts, e.g., SAR for pixel elevation determination, advanced SAR, target polarization effects, etc. The facility would be based on the existing JPL Interim Digital Processor and its modification. It might consist of a general purpose minicomputer augmented by programmable array processors and different display and output peripheral devices. Software developed for this general purpose

facility would also be useful for various simulation and research purposes for radar system technology development. The application of this digital software-based processor is to support various specific and detailed application studies. Its throughput can be limited. The task of processing data in bulk volume remains the function of the optical processing system. Means to improve the performance of the optical processor will also be investigated and implemented to meet the bulk data processing needs. A real time onboard SAR processor may also be developed to facilitate aircraft SAR data acquisition.

2. Definition of SAR processing needs in mid-1980's to support various earth resource application investigations proposed in the 1984 to 1985 time frame. The anticipated radar experiments in this time frame may include systems such as conventional SAR, and burst mode SAR, advanced SAR, multiple-beam SAR, forward or backward looking SAR, radar sounders, etc. Furthermore, they may operate at different frequencies and polarization in a simultaneous manner. Research in this subtask thus consists of efficient processing means for various radar configurations, identification of candidate equipment for data processing, and developing utility software or common hardware module concepts and end-to-end data processing requirements.

3. Development of a high throughput and high quality SAR processor aimed at producing SAR imagery at a very fast turn around time and ready to be analyzed quantitatively to facilitate application studies (where ground-truth of interest may be collected in a timely fashion) as well as the verification of sensor operation and data acquisition during flight.

Besides the laboratory-based SAR data processing facility, this subtask implies the development of a SAR data acquisition system that may feature multiple channel digital data recording equipment funded as part of other radar flight experiments. Processing system upgrade and development will be based on existing equipment. Hardware augmentation and development of new hardware will be anticipated.

This subtask will require 10 man-year per year effort over 3 years, plus a substantial investment in computer facilities. Overall cost is estimated at \$3.5M.

Subtask B: Squint-mode multi-beam SAR and SAW/CCD

Synthetic aperture radar systems are complex, expensive to design and deploy, and produce a tremendous volume of data. In order to place such systems into service in support of earth resources applications programs on an operational basis, a substantial engineering effort will be required. It is important that the engineering effort concentrate on the SAR system as a whole, rather than dividing the problem between the various subsystems. An integrated approach is to optimize overall performance, and at the same time assure that the system be economical to deploy and operate.

A fundamental approach should be adopted in developing new technology for spaceborne systems. New concepts and new configurations should be explored that will allow systems to evolve that are specifically tailored to earth resources applications. Conventional side-looking systems, which represent a technology that grew out of military surveillance requirements, do not necessarily represent the best approach for earth resources mapping.

The squint mode multiple beam concept has been put forth as a superior alternative to conventional SAR systems for earth resources applications. The concept offers the advantages of constant incident angle imaging, reduced transmitter power, relaxed ambiguity constraints, and potentially, simplified image formation processing. Image formation processing for the multiple beam configuration can take advantage of the fact that the system imaging geometry more closely conforms to the natural range-Doppler coordinates of the SAR. Some device technology development will be necessary to fully capitalize on these features.

Device technology development areas include surface acoustic wave (SAW) and charge couples devices (CCD), in addition to the efforts being put forth in digital processing components. The advantages of the analog (SAW) and sampled analog (CCD) technologies, in terms of small size, low power, and real time compatibility, have not yet been exploited to the full extent. One problem has been a difficulty of providing the flexibility and adaptability often required for side-looking systems. The multiple beam processor is more amenable to implementation by these types of devices.

There is need for a comprehensive research program aimed at developing the new technology that will allow SAR systems for earth resources applications to be available when they are needed.

The objective is to develop new SAR concepts and technology with emphasis on a total system approach. The impact of image formation processing on the system should be a major, integral component of the system development.

The justification for a concerted effort in SAR technology development to be started now is that such developments typically take a long time to accomplish. Such a program will assure that system requirements will influence device technology development and help to avoid the situation in which device and implementation technique drive the system design.

The required activities include:

1. Study image formation processing techniques for the squint mode multiple beam SAR configuration. Relate the multiple beam approach to the conventional SAR processor to identify areas of commonality and points of unique advantages for each.

2. Implement or simulate, either via computer or acoustic analog, advanced processor concepts identified above for experimental verification and evaluation against conventional processing systems.

3. Design and fabricate an onboard processing system to be integrated with the Advanced SAR (ASAR) system for operational variation.

4. Evaluate the ASAR processor against spaceborne system design requirements.

This subtask will require a 3-5 man year per year effort over 4 years.

Subtask C: Bistatic radar investigation

The objectives of this subtask are to determine potential utility of oblique scattering angle (bistatic-radar) geometries to earth resources applications, especially with respect to previously unstudied areas of agriculture; hydrology (water, ice, and snow); and land cover, and to refine results with respect to geology.

The approach is to conduct an analytical and conceptual study of problem areas based on current technical literature in radar scatter, including both theoretical and experimental results, to be followed as appropriate by experimental determination of oblique scatter radar signature with respect to parameters of first order importance.

The expected results are:

1. Report detailing findings of analytical and experimental study, with emphasis on experimentally determined variable geometry scattering signatures, and comparison with backscatter results.

2. Possible recommendations for future sensor development, either as new system or in connection with SAR development.

Most active microwave sensing programs to date have concentrated on the use of radar backscatter as the diagnostic parameter. It is well known that radar backscatter is primarily controlled by a combination of target material and shape, and that in general these parameters are not separable in the backscattering case. However, for many types of surfaces the material factors, as expressed in

surface permittivity, and the intermediate scale roughness, i.e., horizontal scales greater than 10-100λ, vertical scales on the order of the wavelength, can be separated based on the use of variable experimental geometry or observations over a range of geometries.

This increased separability of parameters through observations over a range of scattering angles is well known and documented in the theoretical and experimental literature of electromagnetic scatter.

The separability of these factors may be useful in certain areas of remote sensing. As examples, soil moisture content, snow depth, and the height of uniform areas of vegetation might be estimated based on the reflection coefficient of the surface observed in quasi-specular scatter.

The poorly understood variability of radar images with the aspect angle of the viewing suggests that there may be other fundamental advantages to oblique scattering angle geometries. This problem needs study to determine the observational utility of oblique scattering angle geometries with regard to remote sensing problems.

If the results of such a study were favorable to further development for space flight, the geometries needed could be obtained from a dual satellite system, possibly making use of geostationary satellites as a terminus of the radar path. Either SAR or real aperture techniques might be appropriate.

The required activities are:

1. Study utility of oblique scattering angle geometries to define important parameters and possible advantages of oblique scattering angle geometries.

2. Development of real aperture oblique scattering angle radar cross section test range.

3. Study oblique scattering angle geometries and experimentally verify model/analytical results to determine oblique geometry scattering signatures.

This subtask will require a 7-10 man-year effort over a 4 year period, plus the cost of the test facility.

SUMMARY

The technology tasks are necessarily dynamic because of the rapid developments in the applications research areas. Consequently, the objectives and priorities must be reevaluated on a regular basis to assure that the sensor systems and data processing facilities are available to support the needs of the research program. In addition, new technology developments evolve in response to component and materials research development, therefore, NASA should be prepared to respond accordingly.

A problem of critical concern in this area is the heretofore uncoordinated expenditures on technology development within NASA. This report stresses the urgent need to upgrade existing ground-based and aircraft data acquisition systems to support basic research. The total funds devoted to this effort over the last several years has been insignificant compared to the commitment to the Seasat SAR, SIR-A, and Advanced SAR (ASAR), for example. Yet, without support for the basic research effort, it is extremely difficult to justify these expensive SAR systems or to intelligently define future spaceborne SAR systems.

CONCLUSION

The ERSAR Program Definition Working Group structured a research program which addresses the research needs identified by the ERSAR Application Working Group in four discipline areas. This report also specifies the tasks required to bring the technology, i.e. sensor systems, to a stage adequate to support the recommended research program. This program plan is a first-stage definition of the tasks which must be accomplished to establish the measurement capabilities of active microwave remote sensors for earth resources survey applications. The plan will require periodic updating, and the addition of detailed implementation plans. However, the program defined in this report provides an excellent base for a strong research effort in this important sensing techniques area.

The Applications Workshop, November 7-9, 1979, and the Program Definition Workshop, January 23-25, 1980, complete the first phase of the ERSAR Committee activities. The results of these workshops will be used by the Steering Committee to structure an overall program plan to guide the development of this research area.

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ERSAR working group

APPENDIX

ERSAR PROGRAM DEFINITION WORKSHOP

Pasadena, California
January 23-25, 1980

AGENDA

January 23

8:00	Registration
8:30	ERSAR Committee Structure and Objectives - I. Rasool, NASA Headquarters
8:35	Workshop Format and Objectives - Jack Estes, University of California; Pitt Thome, NASA Headquarters
9:15	Workshop Organization and Logistics - Jay Harnage, NASA/Johnson Space Center; Sue Sims, University of Missouri
9:30	Summary of NASA Microwave Remote Sensing Project - James Taranik, NASA Headquarters
10:00	Break
10:15	Summary of ERSAR Applications Workshop - Tony Lewis, Oregon State University
11:30	Lunch
1:00	SEASAT Data - Frank Barath, Jet Propulsion Laboratory
1:30	Status Report on Aircraft Radar Systems - Dick Fenner, Johnson Space Center
2:15	Status Report on Ground-Based Radar Systems - Walt Brown, Jet Propulsion Laboratroy
2:45	Break
3:00	Panel Organization - Keith Carver, New Mexico State University
3:30	Panel Sessions
5:30	Social Hour
6:30	Dinner Break
8:00	Panel Sessions

January 24

8:30	SIR-A Program - Charles Elachi, Jet Propulsion Laboratory
9:30	Panel Sessions
12:00	Lunch
1:30	Panel Reports on Research Needs - Keith Carver, Session Chairman Geology - Stephen Saunders, Jet Propulsion Laboratory Agriculture - Robert MacDonald, Johnson Space Center Land Cover - John Jensen, University of Georgia
2:30	Break
2:45	Panel Reports - continued Water, Ice, & Snow - Albert Rango, Goddard Space Flight Center Technology - Frank Barath, Jet Propulsion Laboratory
3:30	Panel Sessions and Steering Committee
5:00	Dinner Break
8:00	Panel Sessions

January 25

8:30	Panel Reports - S. Rasool, Session Chairman Geology - Stephen Saunders Agriculture - Robert MacDonald
10:00	Break
10:15	Panel Reports - continued Land Cover - John Jensen Water, Ice, & Snow - Albert Rango Technology - Frank Barath
12:15	Summary - S. Rasool
12:30	Adjourn Workshop
1:00	Steering Committee Meeting
2:00	Adjourn Steering Committee Meeting